

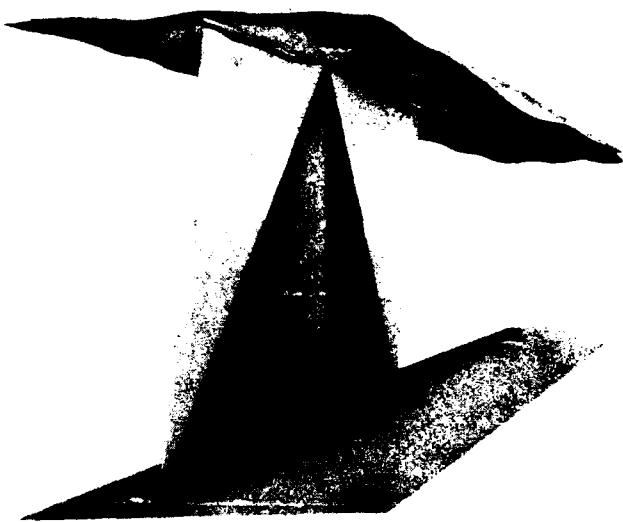
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## "TWIRE:" A Test Program for VLF Airborne Transmissions

R. A. Pappert  
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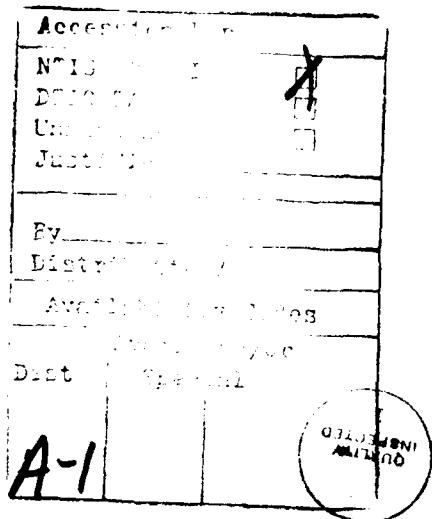
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## 1. INTRODUCTION

Many years ago a computer program was developed at NADC (Huang 1969) which computes the steady state shape of the TACAMO towline assuming an aircraft orbiting in a circular orbit at constant altitude and speed. Although the towline configuration was never checked experimentally, the vertical separation between towplane and conical drogue at the bottom of the towline did compare favorably with a limited number of measurements. Bickel et al (1971) using this code along with a VLF propagation program (Pappert and Shockley 1971) presented some calculations for the vertical electric field at the ground produced by a TACAMO antenna and compared those results with fields generated by an elevated rotating dipole. To the authors' knowledge those are the only long range propagation comparisons made with a rationally determined TACAMO antenna.

The VLF propagation code mentioned above was developed for calculating VLF fields produced by antennas of arbitrary length, shape and elevation. The program was based on simple segmentation of the antenna with each segment acting as a short dipole. The field strength at any distance from the antenna was then calculated as the phasor sum of the contributions from each segment. To perform the calculations presented by Bickel et al (1971), the positions and orientations of the antenna segments had to be manually input to the propagation code along with the current moment for each segment. The latter required an assumed current amplitude and current distribution along the antenna. In particular, no rationale was used to relate current amplitude to radiated power. The latter is generally the quantity assumed in systems calculations.

The purpose of the present report is to describe a computer program called TWIRE which combines several programs and facilitates calculations of the type made by Bickel et al (1971) and which uses as one of its fundamental inputs the power radiated by the antenna. Specifically, TWIRE combines the configuration code of NADC with a simple radiation resistance program (Pappert 1986) and a fast mode conversion propagation code (Ferguson & Snyder, 1980). TWIRE also makes allowance for the counterpoise which is typically about an eighteenth of the rf wavelength (Fern 1986).

As mentioned above, the NADC code calculates the steady state antenna configuration by assuming an aircraft executing a circular orbit at constant altitude and speed. The radiation resistance code assumes a sinusoidal current distribution along the antenna and is strictly valid for a flat infinitely conducting ground. Nevertheless, it is believed to be a reasonable approximation for high conductivity ground (e.g., seawater). Towline plus counterpoise is assumed to be one-half of the rf wavelength. Propagation in either laterally homogeneous or inhomogeneous environments is allowed for by the fast-mode conversion program.

The NADC program determines steady state configurations of the towline from force equations by an iteration procedure which uses as starting conditions the radius and altitude of the conical drogue at the bottom of the towline. To achieve convergence it is generally necessary to begin with good drogue starting conditions. That requirement, unfortunately, prevents full automation of TWIRE. An effective operating procedure is to determine starting conditions by running the NADC code separately for a set of operating conditions, and to then employ those starting conditions in TWIRE.

A brief description of the NADC model is given in the following section. The radiation resistance formula is summarized in section 3 and formulas for mode sums are given in section 4. A brief program description is presented in section 5 and sample input and output is discussed in section 6. Sample results are given in section 7 and a summary including areas of improvement concludes the study in section 8. A listing of TWIRE is given in appendix A and for the purpose of running separately to obtain good drogue starting conditions, the NADC program is listed in appendix B.

## 2. BRIEF DESCRIPTION OF THE NADC MODEL

Several of the assumptions used in constructing the NADC model are (Huang 1969):

1. Towline is inextensible but perfectly flexible.
2. Towplane travels in a perfectly circular path at a constant altitude and speed with no towline pay-out or reel-in.
3. No wind or no wind shear present.
4. Air density varies with altitude as in a standard atmosphere.

Working with a cylindrical coordinate system Huang (1969) derived the steady state configuration of the towline by summing up the forces acting on an element of the towline  $\Delta S$  and equating the sum to zero. His vector force equation is:

$$\frac{\partial \vec{T}}{\partial s} + C_D \rho \frac{d}{2} |\vec{V}_\perp| \vec{V}_\perp + \pi C_f \rho \frac{d}{2} |\vec{V}_{\text{Rel}}| \vec{V}_{\text{Rel}} - \mu g \vec{k} - \mu \frac{\partial^2 \vec{r}}{\partial t^2} = 0, \quad (1)$$

where

$s$  = distance along towline measured from its bottom.

$\vec{T}$  = towline tension at  $s$ .

$d$  = diameter of towline.

$\rho$  = air density.

$\vec{V}_\perp$  = component of the relative air velocity perpendicular to the towline.

$\vec{V}_{\text{Rel}}$  = relative air velocity.

$C_D$  = drag coefficient (dimensionless).

$C_f$  = skin friction coefficient (dimensionless).

$\mu$  = towline mass/unit length.

$g$  = gravitational acceleration.

$\vec{k}$  = unit vector in  $z$  (altitude) direction.

$\vec{r}$  =  $r \vec{u}_r$  = radius vector from axis of rotation to point on towline.

$\vec{u}_r$  = unit vector from axis of rotation to point on towline.

$r$  = towline radius measured from axis of rotation.

When reduced to component form equation (1) becomes (Huang 1969)

$$(TR\gamma)' - Tr(\theta\gamma)^2 + C_D \frac{d}{2} \rho (1 - (r\theta\gamma)^2)^{1/2} r^3 r' \omega^2 \theta' + \mu r \omega^2 = 0 . \quad (2)$$

$$(Tr\theta\gamma)' + Tr'\theta' + \pi C_f \frac{d}{2} \rho (r\omega)^2 - C_D \frac{d}{2} \rho (r\omega)^2 (1 - (r\theta\gamma)^2)^{3/2} = 0 . \quad (3)$$

$$(Tz\gamma)' + C_D \frac{d}{2} \rho r^3 \omega^2 \theta' z' (1 - (r\theta\gamma)^2)^{1/2} - \mu g = 0 . \quad (4)$$

A derivative with respect to  $s$  is indicated by the prime,  $\theta$  is the polar angle,  $z$  the altitude of the towline at position  $s$  and  $\omega$  is the angular speed of the orbiting towplane. Huang (1969) solved these equations by an iteration procedure beginning at the drogue end. As mentioned in the introduction, this generally requires good drogue starting conditions. To complete the description of the problem, force equations and parameters appropriate to the drogue are also required. Unfortunately, the NADC report does not make it clear how the program could be altered to accommodate other drogues, nor is there sufficient discussion to know where many of the drogue parameters came from (presumably some were determined experimentally). Whether or not the equations and parameters used in the NADC report would be suitable, for example, to airborne command post towlines and drogues, is not known.

Under some operating conditions, it is known that two steady state solutions to equations (2) through (4) exist (Huang 1969 and Fern 1986). For the conditions used as examples in the results section of this report, it is believed that only a single solution exists. An often observed operational behavior is a yo-yo effect associated with an orbiting aircraft. Fern (1986) gives an insightful discussion of the effect's origin, pointing out how the lift on the towline varies from upwind to downwind portions of the aircraft orbit and how quite large excursions of the towline could occur if the operating conditions are such that two steady state configurations exist simultaneously. Fern (1986), using the electromagnetic code NEC (Burke and Poggio 1977), also studied electrical properties of the TACAMO antenna. Although superior to the radiation resistance calculation used in this report, NEC would probably be too cumbersome to use in combination with the fast mode conversion program. Perhaps, though, MININEC (Rockway and Logan 1986) could be incorporated in the future.

### 3. RADIATION RESISTANCE

This section contains the formula for the radiation resistance used in this report for thin antennas of arbitrary elevation and orientation over perfectly conducting ground. The formula is based on segmentation of the antenna and figure 1 shows the configuration for the  $n^{\text{th}}$  dipole of current moment  $\bar{M}_n$ . The dipole is located at  $(x_n, y_n, z_n)$  with orientation  $\phi_n$  and  $\gamma_n$  relative to the  $x$  and  $z$  axes, respectively. For the special case of a perfectly conducting ground the time averaged radiated power is (see reference 8):

$$P_w = 30 k^2 \sqrt{\frac{\pi}{2}} \sum_{n,m} M_n M_m \cdot \left\{ \left[ \cos \gamma_n \cos \gamma_m + \frac{1}{2} \sin \gamma_n \sin \gamma_m \cos(\phi_n - \phi_m) \right] (\omega_{nm})^{1/2} J_{1/2}(\omega_{nm}) \right\}$$

$$\begin{aligned}
& + \left[ \cos \gamma_n \cos \gamma_m - \frac{1}{2} \sin \gamma_n \sin \gamma_m \cos(\phi_n - \phi_m) \right] (\omega_{nm}^+)^{1/2} J_{1/2}(\omega_{nm}^+) \\
& + \left[ -\cos \gamma_n \cos \gamma_m + \frac{1}{2} \sin \gamma_n \sin \gamma_m \cos(\phi_n - \phi_m) \right] \\
& \cdot (\omega_{nm})^{3/2} \left[ J_{3/2}(\omega_{nm}) - (z_{nm})^2 (\omega_{nm})^{-1} J_{5/2}(\omega_{nm}) \right] \\
& - \left[ \cos \gamma_n \cos \gamma_m + \frac{1}{2} \sin \gamma_n \sin \gamma_m \cos(\phi_n - \phi_m) \right] \\
& \cdot (\omega_{nm}^+)^{3/2} \left[ J_{3/2}(\omega_{nm}^+) - (z_{nm}^+)^2 (\omega_{nm}^+)^{-1} J_{5/2}(\omega_{nm}^+) \right] \\
& + \left[ \cos \gamma_n \sin \gamma_m \cos(\Phi_{nm} - \phi_m) z_{nm} + \cos \gamma_m \sin \gamma_n \cos(\Phi_{nm} - \phi_n) z_{nm} \right. \\
& + \frac{1}{2} \sin \gamma_n \sin \gamma_m \cos(2\Phi_{nm} - \phi_n - \phi_m) r_{nm} \left. \right] \cdot r_{nm} (\omega_{nm})^{5/2} J_{5/2}(\omega_{nm}) \\
& + \left[ -\cos \gamma_n \sin \gamma_m \cos(\Phi_{nm} - \phi_m) z_{nm}^+ + \cos \gamma_m \sin \gamma_n \cos(\Phi_{nm} - \phi_n) z_{nm}^+ \right. \\
& \left. - \frac{1}{2} \sin \gamma_n \sin \gamma_m \cos(2\Phi_{nm} - \phi_n - \phi_m) r_{nm} \right] r_{nm} (\omega_{nm}^+)^{5/2} J_{5/2}(\omega_{nm}^+) \} . \quad (5)
\end{aligned}$$

where

$$r_{nm} = k \sqrt{(x_n - x_m)^2 + (y_n - y_m)^2}^{1/2}, z_{nm}^\pm = k(z_n \pm z_m), \quad (6)$$

$$\Phi_{nm} = \tan^{-1} \frac{y_n - y_m}{x_n - x_m}, \omega_{nm}^\pm = \sqrt{(z_{nm}^\pm)^2 + r_{nm}^2}^{1/2}. \quad (7)$$

Also,  $k$  is the free space wavenumber and the  $J$ 's are half integer order Bessel functions of the first kind which are expressible in terms of sines and cosines and, therefore, easily calculated. In the case of a single dipole, equation (5) is reduced to the result (the dipole subscript is omitted in (8) and (9) so that  $\gamma$  is the dipole orientation relative to the  $z$  axis):

$$P_w = 20 k^2 M^2 f(z^+, \gamma), \quad (8)$$

where  $z^+ = 2kz$  with  $z$  the dipole height above ground and where

$$\begin{aligned}
f(z^+, \gamma) = & \left[ 1 + \frac{3}{(z^+)^3} (\sin(z^+) - z^+ \cos z^+) \right] \cos^2 \gamma \\
& + \left[ 1 + \frac{3}{2(z^+)^3} ((1 - (z^+)^2) \sin z^+ - z^+ \cos z^+) \right] \sin^2 \gamma. \quad (9)
\end{aligned}$$

To complete the description between radiated power and antenna current, the current distribution is assumed sinusoidal, a reasonable assumption for thin antennas. In particular, as mentioned in the introduction, the towline length plus counterpoise is taken to be one-half of

the free space rf wavelength. That distribution coupled with equation (5) then suffices to determine the current amplitude in terms of the radiated power.

#### 4. MODE SUMS

In the following  $(x, z)$  is the plane of propagation with  $x$  the range coordinate and positive  $z$  directed towards the ionosphere with  $z = 0$  the ground. The  $x$  coordinate of the towplane is taken to be  $x = 0$ . For a slab mode conversion model with  $x_n$  the beginning of the  $n^{\text{th}}$  slab and with the first slab described by the region  $x < x_2$  the mode sums for a  $W$  segmented antenna may be written as

$$E_n^{(1)} = Q \sum_m f_{nm}^{(1)}(z_R) \exp(-ikS_m^{(1)}x) \sum_{w=1}^W \left[ \frac{M_w \exp(ikS_m^{(1)}\bar{x}_w)}{\sin \left[ \frac{x - \bar{x}_w}{a} \right]^{\frac{1}{2}}} \left[ \lambda_{1nm}^{(1)} f_{1m}^{(1)}(\bar{z}_w) \cos \gamma_w \right. \right. \\ \left. \left. + \lambda_{2nm}^{(1)} f_{2m}^{(1)}(\bar{z}_w) \sin \gamma_w \sin \phi_w + \lambda_{3nm}^{(1)} f_{3m}^{(1)}(\bar{z}_w) \sin \gamma_w \cos \phi_w \right] \right], \quad (10)$$

$$E_n^{(p)} = Q \sum_j \sum_m a_{jm}^{(p)} \left[ \delta_{1n} \frac{S_j^{(p)}}{S_m^{(1)}} + (1 - \delta_{1n}) \right] f_{nj}^{(p)}(z_R) \exp(-ik(S_m^{(1)}x_2 + S_j^{(p)}(x - x_p))) \\ \cdot \sum_{w=1}^W \left[ \frac{M_w \exp(ikS_m^{(1)}\bar{x}_w)}{\sin \left[ \frac{(x - \bar{x}_w)}{a} \right]^{\frac{1}{2}}} \left[ \lambda_{1nm}^{(1)} f_{1m}^{(1)}(\bar{z}_w) \cos \gamma_w + \lambda_{2nm}^{(1)} f_{2m}^{(1)}(\bar{z}_w) \sin \gamma_w \sin \phi_w \right. \right. \\ \left. \left. + \lambda_{3nm}^{(1)} f_{3m}^{(1)}(\bar{z}_w) \sin \gamma_w \cos \phi_w \right] \right], \quad p \neq 1, \quad (11)$$

where  $j$  and  $m$  are mode indices and  $w$  is the segment index. The barred quantities represent midpoint values for the  $w^{\text{th}}$  segment. The superscripts denote slab number and the subscript,  $n$ , denotes the electric field component at the receiver with the convention,  $n = 1 \rightarrow EZ$ ,  $n = 2 \rightarrow EY$ ,  $n = 3 \rightarrow EX$ . The  $\lambda$ 's and  $f$ 's are excitation factors and height gains, respectively. The first subscripted index on  $\lambda$  pertains to the orientation of the transmitter with  $\lambda_1$  being the vertical dipole excitation factor,  $\lambda_2$  the broadside excitation factor and  $\lambda_3$  the end-on excitation factor. Similarly,  $f_1$  is the modal height gain for EZ,  $f_2$  the modal height gain for EY and  $f_3$  the modal height gain for EX. With allowance for a different indexing convention and height gain normalization, formulas for the  $\lambda$ 's and the  $f$ 's will be found in reference 9. The  $a_{jm}^{(p)}$  are cumulative mode conversion coefficients and physically represent the accumulative conversion from a unit amplitude wave in mode  $m$  in the transmitter region to mode  $j$  in the  $p^{\text{th}}$  slab. Reference 11 shows how the cumulative conversion coefficients are calculated by the "Fast MC" method. Other quantities appearing in equations (10) and (11) are the dipole moment,  $M$ ; the earth's radius,  $a$ ; the sine of the modal eigenangle,  $S$ ; the free space wavenumber,  $k$ ; the dipole segment orientation factors,  $(\gamma, \phi)$ , defined in the previous section; the receiver altitude,  $z_R$  and  $i = \sqrt{-1}$ . The excitation factors and eigenangle inputs are obtained from the computer code MODESRCH developed by Morsitt and Shellman (1976). With the dipole moment expressed in units of amp-meters and the electric field strength  $E$  in microvolts/m, the constant  $Q$  is

$$Q = 2.853 \times 10^{-3} f^3 \cdot 2 \quad (12)$$

where  $f$  is the frequency in kilohertz.

Equation (10) is used for laterally homogeneous waveguide calculations and equation (11) for laterally inhomogeneous waveguide calculations. Sample results are given in a later section. An additional point is that off axis antenna effects have been ignored in equations (10) and (11). That should be a good approximation for ranges of several hundred kilometers or greater.

## 5. BRIEF PROGRAM DESCRIPTION

Appendix A contains a listing of TWIRE. The nucleus of this code is the FASTMC code (Ferguson and Snyder 1980) and in this section only those program elements of FASTMC which have been altered or program elements which have been added to FASTMC will be discussed.

MAIN controls the program flow. Data is supplied to MAIN via namelist/datum/. The latter is identical to its counterpart in FASTMC. However, the quantities al, incl, theta and talt which appear in namelist are not used in TWIRE. Main calls TACAMO, COORD and RPOWER which are not program elements of FASTMC.

TACAMO is the NADC program for calculating the steady state towline configuration for an aircraft orbiting in a circle at constant altitude and speed. Data is supplied to TACAMO via namelist tacin/. The namelist inputs are:

- v = aircraft speed in knots.
- rpl = aircraft radius in ft.
- zpl = aircraft altitude in ft.
- rzd = drogue starting radius in ft. If not sufficiently close to final iterate the program will abort.
- zzd = drogue starting altitude in ft. If not sufficiently close to final iterate the program will abort.
- amg = drogue weight in lbs (typically  $\approx 100$  lbs).
- psi = rotation angle (degrees) discussed subsequently in connection with the subroutine coord.
- iclock = 0 if aircraft executes a counterclockwise orbit,  $\neq 0$  otherwise.
- itrset = number of times Huang's original iteration scheme is used before changing to a two dimensional Newton iteration which has been added to the original NADC program. Generally, itrset has been set to zero in carrying out the sample calculations in this study.

cpl = counterpoise length in ft.

chicpl = inclination of counterpoise in degrees from horizontal ( $90^\circ \leq \text{chicpl} \leq 0^\circ$  with  $0^\circ$  horizontal and  $90^\circ$  vertical).

Aerodynamic characteristics of the conical drogue, determined by parameters not listed above, are fixed in data statements and were apparently derived from data presented in reference 7. Towline drag and mass coefficients are also fixed in data statements. Lengths of the towline segments in ft. are given in the data statement dstore for segments 1 through 17 and are given by dds for segments greater than 17. These values can be altered to accommodate individual needs.

The Newton iteration mentioned above is developed from the definitions

$$f_1 = z_1(z_d, r_d) - z_{pl} , \quad (13)$$

$$f_2 = r_1(z_d, r_d) - r_{pl} , \quad (14)$$

where  $z_1$  is the iterated plane altitude and  $r_1$  the iterated plane radius corresponding to the starting drogue conditions  $z_d$  and  $r_d$ . Also,  $z_{pl}$  and  $r_{pl}$  are the true plane altitude and radius respectively. Expanding  $f_1$  and  $f_2$  about  $z_d$  and  $r_d$  yields

$$f_1(z_d + \delta z_d, r_d + \delta r_d) \approx f_1(z_d, r_d) + \frac{\partial z_1}{\partial z_d} \delta z_d + \frac{\partial z_1}{\partial r_d} \delta r_d \approx 0 , \quad (15)$$

$$f_2(z_d + \delta z_d, r_d + \delta r_d) \approx f_2(z_d, r_d) + \frac{\partial r_1}{\partial z_d} \delta z_d + \frac{\partial r_1}{\partial r_d} \delta r_d \approx 0 . \quad (16)$$

Solution of equations (15) and (16) gives

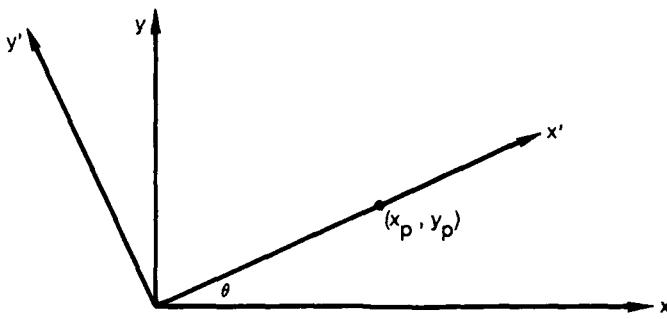
$$\delta z_d = \left( f_2 \frac{\partial z_1}{\partial r_d} - f_1 \frac{\partial r_1}{\partial r_d} \right) / \Delta , \quad \delta r_d = \left( f_1 \frac{\partial r_1}{\partial z_d} - f_2 \frac{\partial z_1}{\partial z_d} \right) / \Delta , \quad (17)$$

$$\Delta = \frac{\partial z_1}{\partial z_d} \frac{\partial r_1}{\partial r_d} - \frac{\partial r_1}{\partial z_d} \frac{\partial z_1}{\partial r_d} . \quad (18)$$

TACAMO is also included as a separate entry in Appendix B. As mentioned previously, it is best when working with new operating conditions to run TACAMO by itself to get starting conditions for TWIRE. A possible step to fuller automation would be to develop a multidimensional grid of starting values for a cross section of operating conditions and to use interpolation to determine drogue starting values for intermediate operating conditions. In that connection, operating frequencies range from about 17 kHz to 30 kHz and TACAMO aircraft generally operate at air speeds between about 170 and 250 knots at altitudes between about 20,000 and 40,000 ft. with radii  $> 4,000$  ft. (Fern 1986).

COORD performs the following coordinate transformations. In the schematic below, the towplane's (x,y) coordinates are denoted by  $(x_p, y_p)$ . The axis are first rotated by the angle  $\theta = \tan^{-1}(y_p/x_p)$ , so that in the  $x'$ ,  $y'$  system  $y'_p = 0$ .

The  $y'$  axis is the direction of the towplane for counterclockwise rotation (i.e., iclock = 0). Coordinates of the point  $(x, y)$  in the unprimed system become in the prime system



$$x' = x \cos \theta + y \sin \theta, \quad (19)$$

$$y' = -x \sin \theta + y \cos \theta. \quad (20)$$

The prime coordinate system is next translated so that the towplane is at the origin. That is

$$x'_T = x' - x'_p, \quad (21)$$

$$y'_T = y'. \quad (22)$$

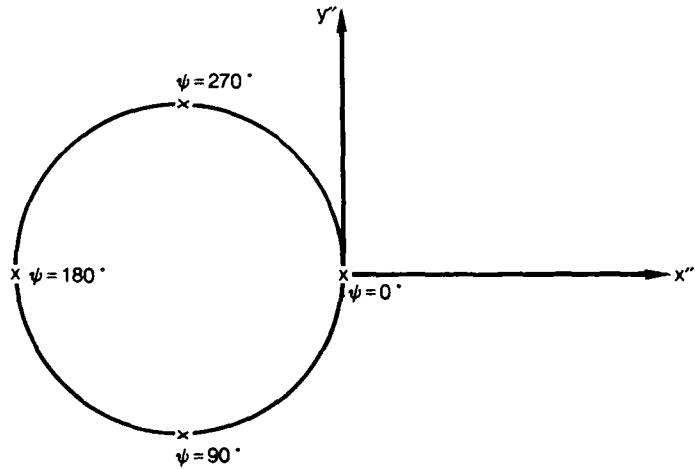
If the airplane is moving in a clockwise rotation (iclock = 1), the  $y'$  coordinates are reversed in sign. Let  $\psi$  (psi) be the direction between the  $x'$  direction (i.e., direction from center of orbit to towplane) and the direction of propagation, denoted by  $x''$ .

Then,

$$x'' = x'_T \cos \psi + y'_T \sin \psi, \quad (23)$$

$$y'' = -x'_T \cos \psi + y'_T \sin \psi. \quad (24)$$

Values of  $\psi$  at cardinal points on the orbit with  $x''$  directed to the right are indicated below.



The counterpoise coordinates are also calculated in COORD subject to the assumption that the counterpoise is in the direction  $-\vec{v}/|\vec{v}|$ , where  $\vec{v}$  is the towplane's velocity and droops at an angle chcp with the horizontal.

RPOWER is the program element where equation (5) is implemented subject to the assumption that the antenna length plus counterpoise is one-half the rf wavelength and that the current is sinusoidally distributed. Outputs of the subroutine are the current moments (idl) of the antenna segments for a given radiated power input, pin.

MCFLDS is an original program element of the program FASTMC which in TWIRE has been modified to allow for antenna segmentation. If iopt = 1 (range option flag), MCFLDS is called from MAIN for each range between dmin and dmax at deltad intervals and the electric field components EZ or EY are computed according to equations (10) or (11). Field values in complex form are contained in SUMOUT and field amplitudes in Amp. If iopt = 2 (height gain option), MCFLDS is used as an intermediate step in calculating the electric field components. Final field calculations in this instance are performed in MAIN. Again, field values in complex form are contained in SUMOUT and field amplitudes in Amp.

## 6. SAMPLE INPUT AND OUTPUT

Three files are required for input to TWIRE. The three files are called twzy.in, twzy.com and cards.30. They represent input for a range calculation of the vertical electric field component EZ and the horizontal electric field component EY for a laterally homogeneous guide. The file twzy.in first calls for the file twzy.com and then for data contained in namelist tacin, which is used for the towline configuration calculation. Listed in order in namelist tacin are:

v = towplane velocity in knots.  
rpl = towplane radius in feet.  
zpl = towplane altitude in feet.  
rzd = drogue starting radius in feet.  
zzd = drogue starting altitude in feet.  
amg = drogue weight in pounds.  
psi = angle in degrees between radius vector from center of towplane's orbit to towplane and the direction of rf propagation.  
iclock = flag for clockwise (1) or counterclockwise (0) towplane rotation.  
chcp = droop angle of the counterpoise measured in degrees from the horizontal.  
cpl = counterpoise length in feet.

The namelist tacin is then repeated a second time as the configuration calculation is repeated for each component calculated.

The file twzy.com begins with the character string "name". Its remaining contents in this instance are:

rcomp = electric field component calculated (1 for EZ, 2 for EY).  
nprint = printout flag  
= 0 none  
= 1 slab identification data and field amplitude and phase  
= 3,4 intermediate mode conversion data used for diagnostics only.  
naplot = 0 amplitude plot flag (0 for no plot, 1 for plot).  
dmin = minimum range in Mm.  
dmax = maximum range in Mm.  
nrptsl = number of ranges calculated at equal increments between dmin and dmax.  
ampmax = upper limit of field amplitude plot dB/ $\mu$ V/m.  
ampmin = lower limit of field amplitude plot in dB/ $\mu$ V/m.  
ralt = receiver altitude in km.  
cards.30 = waveguide mode constant data (see e.g., reference 6).

The calculations are repeated for rcomp = 2 (i.e., for EY calculations).

The waveguide input file, cards.30, obtained from reference 6 begins with DATA followed by a descriptor title. The next line identifies the slab properties as follows:

R = range location of slab in km.  
F = frequency in kHz.  
A = propagation azimuth from magnetic north (degrees).  
C = geomagnetic field codip (degrees).  
M = geomagnetic field strength (W/m<sup>2</sup>).  
S = ground conductivity (S/m).  
E = ground dielectric constant.  
T = Top height used for waveguide calculations (km).

INPUT FILE: TWZY.IN

```
twzy.com
&tacin
v-200.,
rpl-4000.,
zpl-20000.,
rzd-700.0,
zzd-9000.,
amg-100.,
psi-180.0,
iclock-0,
chicp-0.,
cpl-1800.,
&end
y
y
&tacin
v-200.,
rpl-4000.,
zpl-20000.,
rzd-700.0,
zzd-9000.,
amg-100.,
psi-180.0,
iclock-0,
chicp-0.,
cpl-1800.,
&end
```

INPUT FILE: TWZY.COM

```
name
&datum rcomp=1,nprint=1,naplot=0,
dmin=0.000,dmax=5.000,
nrpts1=11,
ampmax=80.,ampmin=0.,
ralt=9.144, &end
input cards.30
name
&datum rcomp=2,&end
start
quit
```

INPUT FILE: CARDS.30

DATA

towline test

R .000 F 30.0000 A 90.000 C 40.000 M .500E-04 S 4.640E+00 E 81.0 T 87.0  
 1 89.97300 -6.722872 1.14900804E-05-9.69784160E-05-5.66454815E-13 8.91278878E-16  
 2 89.97300 -6.722872 4.94460073E-09 5.55613688E-09 1.00000072E+00-7.01791265E-08  
 1 89.79732 -6.138471 1.39372627E-04-4.28004772E-04-9.34471576E-13-3.41234067E-13  
 2 89.79732 -6.138471-9.26029919E-09-1.90273877E-08 1.00000119E+00 9.79737678E-08  
 1 89.91204 -3.159701-5.67914452E-04-1.12545611E-02-4.18753747E-12-1.40717722E-12  
 2 89.91204 -3.159701 1.34759489E-07 1.77823267E-C7 1.00000048E+00-4.46208873E-07  
 1 88.82600 -1.083422 2.33682222E-03-5.44904545E-03-2.69803867E-11-6.00914040E-14  
 2 88.82600 -1.083422-2.19763109E-07-3.34162451E-07 1.00000072E+00 7.85546206E-09  
 1 84.71127 -.222291-2.45107268E-03-1.99295953E-02-1.35681544E-11-9.35714700E-12  
 2 84.71127 -.222291 2.98093312E-07 4.92028562E-07 1.00000048E+00 2.00596716E-07  
 1 82.74648 -.273032 2.91138096E-03-4.90130810E-03-1.01852499E-10 9.41601918E-12  
 2 82.74648 -.273032-4.07881686E-07-6.45559965E-07 1.00000012E+00-5.70226248E-08  
 1 80.40218 -.234551-3.23274592E-03-1.51210632E-02-5.33708217E-11-3.51053041E-11  
 2 80.40218 -.234551 5.61018396E-07 8.20390710E-07 1.00000036E+00 1.91906668E-08  
 1 78.70553 -.293832 3.81615874E-03-6.45386567E-03-1.83607657E-10 3.90313511E-11  
 2 78.70553 -.293832-6.92323852E-07-9.63369075E-07 1.00000048E+00 2.79036698E-07  
 1 76.58138 -.261791-4.16685035E-03-1.15461908E-02-1.42259260E-10-8.68795105E-11  
 2 76.58138 -.261791 9.04359183E-07 1.10827352E-06 9.99999583E-01 3.27973055E-07  
 1 74.96912 -.345282 4.87595052E-03-8.77621677E-03-2.45324872E-10 9.70813221E-11  
 2 74.96912 -.345282-1.07347228E-06-1.22331073E-06 9.99999821E-01 4.46039110E-07  
 1 72.92796 -.296672-5.04938047E-03-8.35422613E-03-3.03403247E-10-1.68299430E-10  
 2 72.92796 -.296672 1.32530784E-06 1.27687861E-06 1.00000048E+00 9.59014642E-07  
 1 71.32272 -.409471 5.76619152E-03-1.14735551E-02-2.64180205E-10 1.84621096E-10  
 2 71.32272 -.409471-1.53844314E-06-1.33109688E-06 1.00000048E+00 9.05900492E-07  
 1 69.33108 -.339462-5.64039499E-03-5.37072308E-03-5.54849555E-10-2.73569306E-10  
 2 69.33108 -.339462 1.79977269E-06 1.25654230E-06 9.99999106E-01 1.31630159E-07  
 1 67.68570 -.479001 6.25931984E-03-1.42788989E-02-2.23180446E-10 2.91375785E-10  
 2 67.68570 -.479001-2.05986134E-06-1.21624373E-06 9.99997795E-01 2.21355563E-07  
 1 65.73211 -.392672-5.82792237E-03-2.63220887E-03-9.07945108E-10-3.89095423E-10  
 2 65.73211 -.392672 2.30049409E-06 1.01230273E-06 9.99995053E-01-3.48421486E-06  
 1 64.01385 -.546571 6.22112770E-03-1.70211233E-02-1.11896700E-10 3.96509547E-10  
 2 64.01385 -.546571-2.59987064E-06-8.40697567E-07 1.00000191E+00-1.35956998E-05  
 1 62.08826 -.459332-5.56169311E-03-1.49533094E-04-1.37232026E-09-4.94906449E-10  
 2 62.08826 -.459332 2.79967230E-06 5.28230146E-07 1.00002074E+00 2.41414864E-06

r 40.0

ramax = maximum receiver altitude in km (used with iopt = 2).

ratic = tic mark spacing on receiver altitude scale (used with iopt = 2).

dist = range locations in Mm at which height gains are calculated (used with iopt = 2).

nrd = numbers of dist (used with iopt = 2).

nrpts2 = number of height gain points calculated between ramin and ramax (used with iopt = 2).

Following the quantities contained in the datum namelist, comes the slab identification data described previously and the tacin namelist data also described previously (except for itrset which controls the iterations as described in section 5 — default is 0). Apart from input quantities discussed in connection with namelist tacin, the following appear:

abase = base area of drogue in sq. ft.

cddrog = drogue drag coefficient.

amug = towline weight lbs/ft.

d = towline diameter in ft.

al = towline length in ft.

dds = a spacing increment along the towline in ft.

picf = towline skin friction coefficient.

cd = towline drag coefficient.

All of the above, except al, are set in data statements in the subroutine TACAMO. The quantity al is calculated subject to the condition that the towline length plus counterpoise is one-half a rf wavelength.

Following the slab identification card is the mode data. Each eigenangle in degrees appears twice along with four complex quantities from which all excitation factors are calculated. The cards.30 file is terminated with the r = 40.0 character string. If more slabs were used in the modeling (i.e., lateral inhomogeneity allowed for) then slab identification and data for each additional slab would follow in order with a space separating each new slab entry beginning with the range information (R etc.) record.

Output corresponding to the preceding input is shown on pages 16 through 21. The output first echoes the namelist datum. Quantities not specified in the datum entry in twzy.com appear in the output along with their default values. In order, quantities not discussed in connection with the input are (also see reference 3):

iopt = range or height gain option flat (1 for range, 2 for height gain).

al, incl, theta, talt, TOPHT = quantities not used as input in TWIRE.

npplot = phase plot flag (0 no plot, 1 plot).

npdiff = not used in present program.

nrcurv = number of curves on a plot (maximum of 4).

sizex = size of x axis in inches.

sizey = size of y axis in inches.

amptic = tic mark spacing on amplitude axis.

phsmax = phase axis maximum in degrees.

phsmin = phase axis minimum in degrees.

phstic = tic mark spacing on phase axis.

dtic = tic mark spacing in Mm on range axis.

tlong, tlat, rbear, totape = not used in TWIRE.

power = radiated power in kw.

ramin = minimum receiver altitude in km (used with iopt = 2).

The towline configuration follows and is described by:

s = distance in feet along towline as measured from its bottom.

r = radius of towline in feet at s.

z = altitude of towline in feet at s.

th = azimuth of towline in radians measured in counterclockwise direction at s.

The remaining quantities t, rp, zp and rthp are of no interest in the present application. In the output it will be seen that the program iterated twice, there being three sets of s, r, z and th values given at the bottom and top of the towline. Final values calculated from the bottom to the top follow. Next comes imid which is the towline segment where the current is a maximum. The midpoint coordinates are listed for each segment after the coordinate transformations discussed in section 5 have been made. Also listed is gamma and phi for each segment where gamma is the inclination in degrees of the segment from vertical and phi is its azimuth in degrees. Following the midpoint information is a printout of the electric field component being calculated and the receiver altitude. The principal output then follows showing dist in Mm, field amplitude in dB/ $\mu$ V/m and its phase in degrees. The output then repeats itself for the second field component, EY.

## OUTPUT FILE

name SDATUM  
 TOPT = 14  
 RCOMP = 0.000000E+00  
 AL = 0.000000E+00  
 DNCL = 0.000000E+00  
 THETA = 0.000000E+00  
 TALT = 0.000000E+00,  
 RALT = 9.14400005,  
 TOPT = 90.0,  
 NAPLOT = 0,  
 NPOLIT = 0,  
 NPRINT = 1,  
 NRCURV = 1,  
 SIZEX = 5.0,  
 SIZEY = 6.0,  
 ANPEMAX = 80.0  
 ANPEMIN = 0.000000E+00,  
 ANPTIC = 10.0  
 PHSMAX = 360.0  
 PHSMIN = -360.0,  
 PHSTIC = 90.0,  
 DMAX = 5.0  
 DMIN = 0.000000E+00,  
 DTIC = 1.0  
 TLONG = 0.000000E+00,  
 TLAT = 0.000000E+00,  
 FBEAR = 0.000000E+00,  
 POWER = 1.0,  
 TOTAPE = 0  
 NRPTS1 = 11  
 RAMIN = 0.000000E+00,  
 RAMAX = 50.0,  
 RATTIC = 5.0  
 DIST = 0.000000E+00, 0.000000E+00, 0.000000E+00, 0.000000E+00,  
 0.000000E+00, 0.000000E+00, 0.000000E+00, 0.000000E+00,  
 0.000000E+00, 0.000000E+00, 0.000000E+00, 0.000000E+00,  
 0.000000E+00, 0.000000E+00, 0.000000E+00, 0.000000E+00,  
 NRD = 0, NRPTS2 = 51  
 Send  
 Input cards. 30  
 DATA  
 towline test  
 Slab 1 R 000 F 30.0000 A 90.000 C 40.000 M 500 S 4.640E+00 E 81.0 T 87.0  
 Insufficient number of slabs, horizontally homogeneous only  
 STACIN  
 V = 200.0  
 RPL = 4000.0,  
 ZPL = 2000.0,  
 RZD = 700.0,  
 ZZD = 900.0,



## OUTPUT FILE (CONTINUED)

|    |                        |              |           |           |           |
|----|------------------------|--------------|-----------|-----------|-----------|
| 4  | 4031.104               | -706.514     | 9295.523  | 13.616    | 39.187    |
| 5  | 4071.887               | -676.366     | 9488.878  | 15.806    | 34.128    |
| 6  | 4119.192               | -645.224     | 9680.599  | 17.204    | 32.436    |
| 7  | 4170.580               | -612.793     | 9871.172  | 18.074    | 32.282    |
| 8  | 4216.866               | -569.909     | 10108.325 | 18.640    | 33.301    |
| 9  | 4316.654               | -515.276     | 10392.220 | 18.987    | 35.481    |
| 10 | 4394.909               | -456.552     | 10675.718 | 19.104    | 38.281    |
| 11 | 4470.218               | -393.109     | 10959.109 | 19.123    | 41.521    |
| 12 | 4552.580               | -314.074     | 11289.741 | 19.100    | 45.842    |
| 13 | 4639.201               | -215.955     | 11667.590 | 19.151    | 51.274    |
| 14 | 4716.023               | -109.182     | 12045.240 | 19.305    | 57.235    |
| 15 | 4781.598               | 6.547        | 12422.377 | 19.607    | 63.643    |
| 16 | 4842.999               | 165.626      | 12892.170 | 20.260    | 72.285    |
| 17 | 4888.013               | 373.282      | 13452.779 | 21.420    | 82.969    |
| 18 | 4875.182               | 681.105      | 14189.255 | 23.711    | 97.507    |
| 19 | 4750.215               | 1089.204     | 15088.847 | 27.589    | 115.286   |
| 20 | 4469.080               | 1495.129     | 15951.461 | 32.566    | 132.807   |
| 21 | 4018.064               | 1846.740     | 16761.982 | 38.460    | 150.065   |
| 22 | 3406.158               | 2079.605     | 17504.593 | 44.976    | 167.169   |
| 23 | 2673.062               | 2129.689     | 18165.823 | 51.681    | -175.876  |
| 24 | 1888.200               | 1950.678     | 18738.163 | 58.075    | -159.094  |
| 25 | 1118.123               | 1528.149     | 19222.350 | 63.723    | -142.580  |
| 26 | 506.998                | 884.130      | 19627.093 | 68.347    | -126.555  |
| 27 | 115.445                | 255.867      | 19905.950 | 71.337    | -114.284  |
| 28 | 0.001                  | 900.000      | 20000.764 | 90.000    | 90.000    |
| 2  | COMP                   | RALT = 9.144 | DIST      | AMPLITUDE | PHASE     |
| 3  | DIST                   | AMPLITUDE    | PHASE     | DIST      | AMPLITUDE |
| 4  | 0.000                  | 99.9900      | 1.500     | 49.1092   | 45.2930   |
| 5  | 0.500                  | 54.3566      | 2.000     | 52.4274   | 45.3529   |
| 6  | 1.000                  | 29.7413      | 2.500     | 35.2352   | 44.8034   |
| 7  | 1                      | name         |           |           |           |
| 8  | SDATUM                 |              |           |           |           |
| 9  | TOPIT = 1              |              |           |           |           |
| 10 | RCOMP = 2              |              |           |           |           |
| 11 | AL = 0.000000E+00      |              |           |           |           |
| 12 | INCL = 0.000000E+00    |              |           |           |           |
| 13 | THETA = 0.000000E+00   |              |           |           |           |
| 14 | TALT = 0.000000E+00    |              |           |           |           |
| 15 | RALT = 9.14400005,     |              |           |           |           |
| 16 | TOPIT = 90.0,          |              |           |           |           |
| 17 | NAPLOT = 0,            |              |           |           |           |
| 18 | NPLOT = 0,             |              |           |           |           |
| 19 | NPDIFF = 0,            |              |           |           |           |
| 20 | NPRINT = 1,            |              |           |           |           |
| 21 | NRCURV = 1,            |              |           |           |           |
| 22 | SIZEX = 5.6,           |              |           |           |           |
| 23 | SIZEY = 6.0,           |              |           |           |           |
| 24 | AMENMAX = 80.0,        |              |           |           |           |
| 25 | AMENIN = 0.000000E+00, |              |           |           |           |
| 26 | AMETIC = 10.0,         |              |           |           |           |
| 27 | PHSMAX = 360.0,        |              |           |           |           |
| 28 | PHSMIN = -360.0,       |              |           |           |           |
| 29 | PHSTIC = 90.0,         |              |           |           |           |



## OUTPUT FILE (CONTINUED)

OUTPUT FILE (CONTINUED)

|       |         |           |       |         |          |       |         |           |       |
|-------|---------|-----------|-------|---------|----------|-------|---------|-----------|-------|
| .000  | 99.9900 | 0.0000    | 1.500 | 43.8222 | 5.9773   | 3.000 | 38.5422 | -102.1602 | 4.500 |
| .500  | 55.1470 | -107.5491 | 2.000 | 38.6708 | 47.5314  | 3.500 | 38.9922 | -47.7427  | 5.000 |
| 1.000 | 52.0568 | -41.7453  | 2.500 | 36.1082 | -38.3315 | 4.000 | 36.0473 | -3.8035   |       |

1 quit  
End of job, 0 curves plotted in 0 graphs

## 7. SAMPLE RESULTS

Shown in figures 2 through 5 are drogue altitude and drogue radius for towline lengths ranging between 14,000 and 30,000 ft. The figures apply to a towplane altitude of 30,000 ft and speed of 200 knots. Figure 2 is for a towplane radius,  $r_d$ , of 4000 ft., figure 3 for  $r_d$  = 6000 ft., figure 4 for  $r_d$  = 8000 ft. and figure 5 for  $r_d$  = 30,000 ft. which approximates straight flight. These curves can be used to obtain starting conditions for other operating conditions by gradually evolving from the conditions of the figures to the desired operating conditions (the procedure can be very tedious in some instances). As mentioned previously, a possible step to fuller automation of the present program would be to develop a multidimensional grid of starting values for a variety of operating conditions, of which figures 2 through 5 are a sample, and to use interpolation to determine drogue starting conditions for intermediate operating conditions.

It will be seen that there is a rapid change in drogue radius and altitude which occurs for a towline length of about 16,500 ft. in figure 3 and for a towline length of about 21,500 ft. in figure 4. On the basis of the examination made in this study it does not appear that there are two solutions in the neighborhood of those points and the physical origin of the rapid changes is not known.

It is known that a simple exponential  $\beta = 0.5 \text{ km}^{-1}$ ,  $h' = 87 \text{ km}$  (notation of Wait & Spies, 1964) profile does an excellent job of predicting nocturnal VLF propagation to the east (Pappert and Hitney 1988). Figures 6 through 13 show results for the vertical electric field at the ground generated by a TACAMO antenna under several operating conditions. The results are for easterly propagation (azimuth =  $90^\circ$ ) and the  $\beta = 0.5 \text{ km}^{-1}$ ,  $h' = 87 \text{ km}$  profile. For all of the figures a seawater path is assumed (i.e., conductivity =  $4.64 \text{ s/m}$ , relative permittivity = 81) and the geomagnetic field strength is taken to be 0.5 Gauss with a dip of  $50^\circ$ . Also, for all figures the towplane's speed is taken to be 200 knots. Figures 6 through 9 are for 20 kHz whereas figures 10 through 13 are for 30 kHz. Results are given for towplane altitudes (Aalt) of 20,000 and 30,000 ft. and for towplane radii (Rpl) of 4000 and 8000 ft. The counterpoise length has been taken to be 1800 ft. at 30 kHz and 2800 ft. at 20 kHz. All of the figures apply to counter-clockwise rotation ( $I_{clock} = 0$ ) with  $\psi = 0^\circ$  (see section 5) and a radiated power (Pwr) of 1 kW. Also shown on the curves are results for point dipole calculations with altitude and angular orientation factors for the point dipole determined by the towline segment which contains the current maximum (i.e.,  $i_{mid}$  discussed in section 6). In calculating the point dipole results, allowance has been made for its radiation resistance dependence on height and tilt relative to the z axis as expressed by equation (9). Except in rare instances the point dipole results agree with the TACAMO antenna calculation to better than 2 dB and the results are almost indistinguishable in figures 6 and 8. Interestingly these are the cases of high verticality or low  $\gamma$ 's.

Although probably not as much of interest as the air-to-ground transmission of EZ just discussed, figures 14 through 21 show results for the transverse electric (TE) field component EY at 30,000 ft (i.e., Ralt = 30.00). Other than the receiver altitude difference, the results are for the same set of operating conditions which applied to figures 6 through 13. Shown again are results for the point dipole. It will be seen that except in rare instances the shapes of the mode sum plots for the TACAMO antenna and point dipole calculations are very similar. Agreement in terms of absolute dB levels is not quite as good in this instance as it was for the EZ component and there are occurrences where the signal levels differ by 10 dB or more.

Although the  $\beta = 0.5 \text{ km}^{-1}$ ,  $h' = 87 \text{ km}$  profile does not accurately predict westerly propagation (Pappert and Hitney 1988), figures 22 through 25 are presented as illustrating, for that direction (azimuth =  $270^\circ$ ) and profile, comparisons between the TACAMO antenna and point dipole calculations. Figures 22 and 23 show results for Ez at the ground at 20 kHz with the towplane altitude 20,000 ft. Figure 22 gives results for the towplane radius of 4000 ft. and

figure 23 gives results for the towplane radius of 8000 ft. The TACAMO and point dipole results for the high verticality (low  $\gamma$ ) case are in very good agreement. The TACAMO and point dipole results for the low verticality case (high  $\gamma$ ) shown in figure 23 do not agree as well in this instance as they did for the corresponding easterly propagation case (figure 7). It is known that the VLF fields penetrate to higher altitudes for westerly propagation than they do for easterly propagation. Thus, the modes are more hybrid for westerly propagation and that may be partly responsible for the larger differences noted for the low verticality westerly propagation.

Figures 24 and 25 show results for EY at 30,000 ft. at 20 kHz with the towplane altitude 20,000 ft. Figure 24 gives results for the towplane radius of 4000 ft. and figure 25 gives results for the towplane radius of 8000 ft. Again, the TACAMO and point dipole calculations for the high verticality (low  $\gamma$ ) case are in very good agreement. The differences between the TACAMO and point dipole calculations shown in figure 25 for the low verticality (high  $\gamma$ ) case appear to be comparable to those for the corresponding easterly propagation case (figure 15).

Figures 26 and 27 compare signal levels for easterly propagation for  $\psi = 90^\circ$  and  $270^\circ$ . The results apply to a frequency of 30 kHz with the towplane at 20,000 ft. and in an orbit of radius 4000 ft. Figure 26 is for EZ at the ground and figure 27 is for EY at 30,000 ft. Differences between the curves are measures of the orbital modulation expected as the towplane executes its orbit. The modulation expected is one maximum and one minimum associated with each rotation of the towplane. In rare instances, the minimum field occurs for  $\psi$ 's close to  $0^\circ$  and  $180^\circ$ . Based on curves not shown such a circumstance for the EY component occurs in the present example at a range of 1.425 Mm. The expected modulation in this case is two maxima and two minima during the course of one rotation of the towplane. Examples of each type of modulation are shown in figure 28. The amplitude excursions at 2.6 Mm for EZ and at 2 Mm for EY are consistent with expectations based on figures 26 and 27 respectively.

The preceding results have all been for laterally uniform waveguides. Results for a laterally nonuniform waveguide are shown in figures 29 and 30. The guide is characterized by waveguide modes corresponding to an azimuth of  $90^\circ$  out to 2 Mm, between 2 Mm and 4 Mm the waveguide modes are taken to be those corresponding to an azimuth of  $270^\circ$  and beyond 4 Mm the waveguide modes are again taken to be those characterized by an azimuth of  $90^\circ$ . The electron density in each slab is described by the  $\beta = .5 \text{ km}^{-1}$ ,  $h' = 87 \text{ km}$  profile used previously. Also, the geomagnetic field magnitude and dip as well as the ground parameters are identical to those used previously. Although such a waveguide is physically unrealistic it can be used as a check on the performance of the program for a laterally inhomogeneous environment. Figure 29 provides results at 30 kHz for EZ at 30,000 ft. The towplane's altitude is 30,000 ft., its radius is 4000 ft. and its speed is 200 knots. Figure 30 gives results at 30 kHz for the EY component at 30,000 ft. for the same towplane conditions. Also, shown on the plots are the point dipole results. The good agreement between the TACAMO antenna results and the point dipole results serves as a check on the performance of TWIRE in a laterally inhomogeneous environment.

## 8. SUMMARY AND AREAS OF IMPROVEMENT

A computer program called TWIRE, which combines a TACAMO antenna configuration code (Huang 1969), a radiation resistance code (Pappert 1986) and a VLF propagation code (Ferguson and Snyder 1980), has been assembled for the purpose of conducting case studies for VLF airborne transmissions and for the purpose of pointing out possible areas of improvement for calculating such transmissions. In particular, by combining the three codes TWIRE provides a tool for conducting VLF airborne transmission studies based on a rationally determined antenna configuration. A major deficiency of the program is that it is not fully automated because the configuration code requires initial inputs which often have to be determined in advance. A possible scheme for overcoming that deficiency would be to provide a multidimensional grid of starting conditions for different operating conditions (i.e., towline length and towplane's altitude, speed and radius) and to use an interpolation scheme for intermediate operating conditions. One problem that would have to be resolved in connection with this approach would be the resolution of how to handle operating conditions when more than one stable towline configuration exists. Other areas of improvement relate to a fuller treatment of the dynamics of the towline. The possibility of extending the steady state NADC model to include transient and wind effects is such an area. Also, the NADC report does not fully describe the origin of the drogue parameters and formulas which provide crucial starting conditions for the integrations necessary to determine the towline configuration. It is not clear, therefore, how to adapt the NADC program to airborne systems other than TACAMO. Better documentation of the NADC code would, therefore, be of value.

Because of simplifications used in the development of the radiation resistance calculations, TWIRE is strictly valid for infinite ground conductivity. This is probably the easiest element to improve. It is quite likely that approximate allowance for finite ground conductivity could be made without increasing cpu time. It is even possible that MININEC could be incorporated in place of the program element RPOWER.

In the present study, the principle objective has been to illustrate the feasibility of performing VLF airborne transmissions for a rationally determined antenna configuration without specific regard to cpu time. It is quite possible that TWIRE can be speeded up by simply rearranging do loops involving sums over modes and antenna segments.

Perhaps the greatest utility of TWIRE will be to simply assess the adequacy, for field calculation purposes, of point dipoles as approximations to TACAMO configurations. For example, limited results given in section 7 would indicate that a sensibly chosen point dipole would suffice for many, if not most, systems applications.

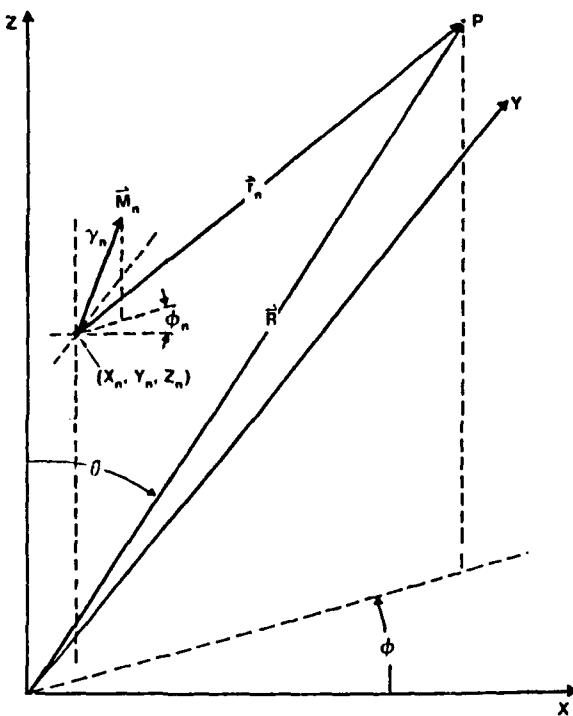


Figure 1. Dipole geometry.

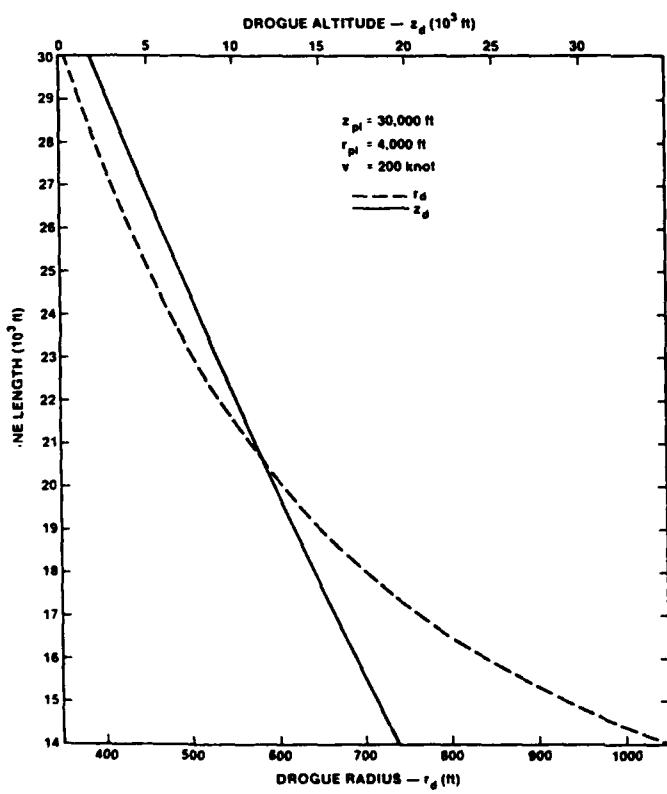
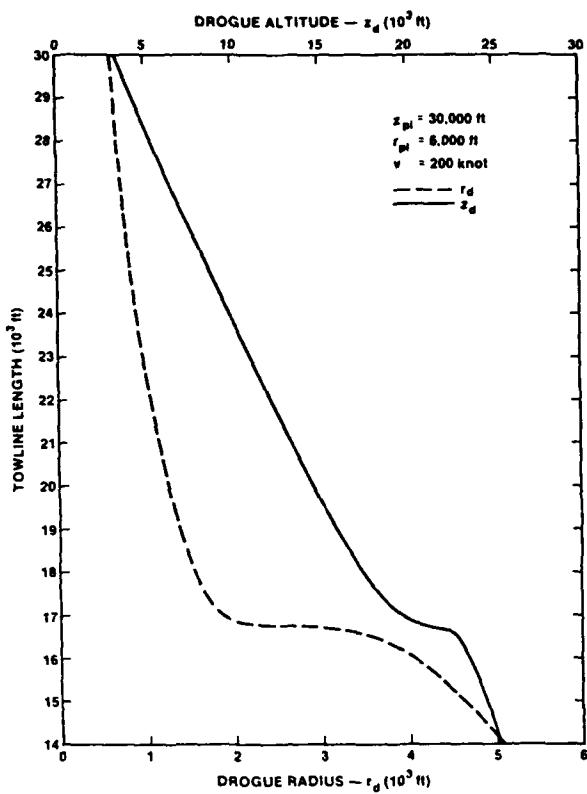
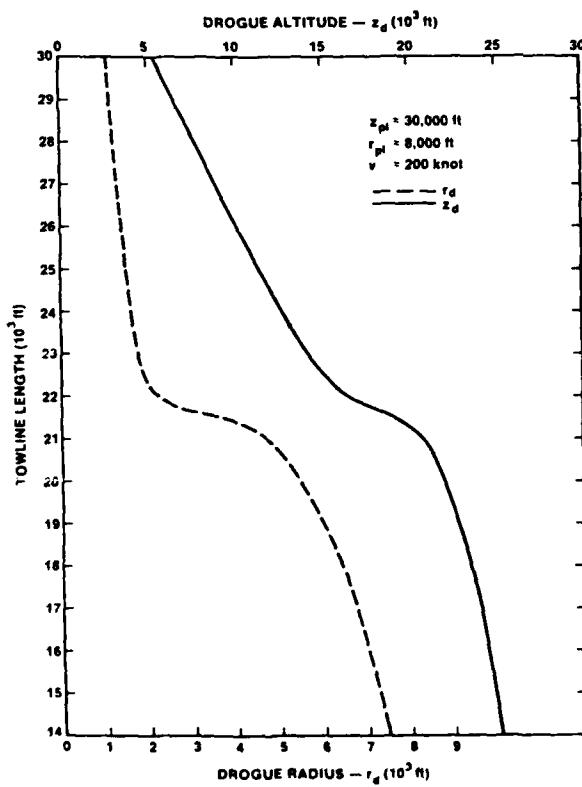


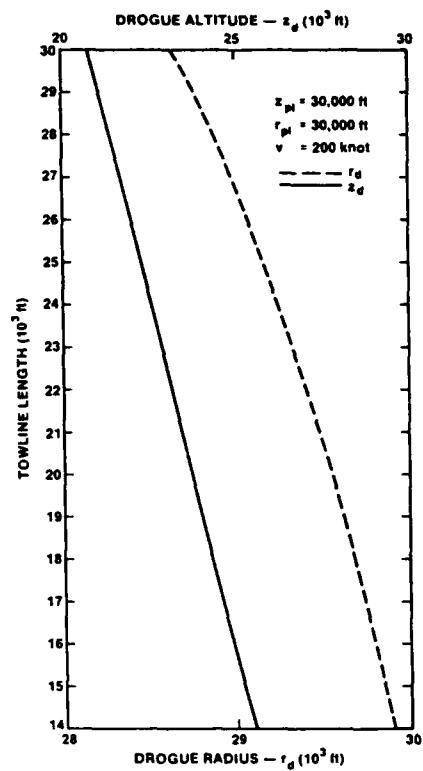
Figure 2. Towline length vs. drogue starting conditions.



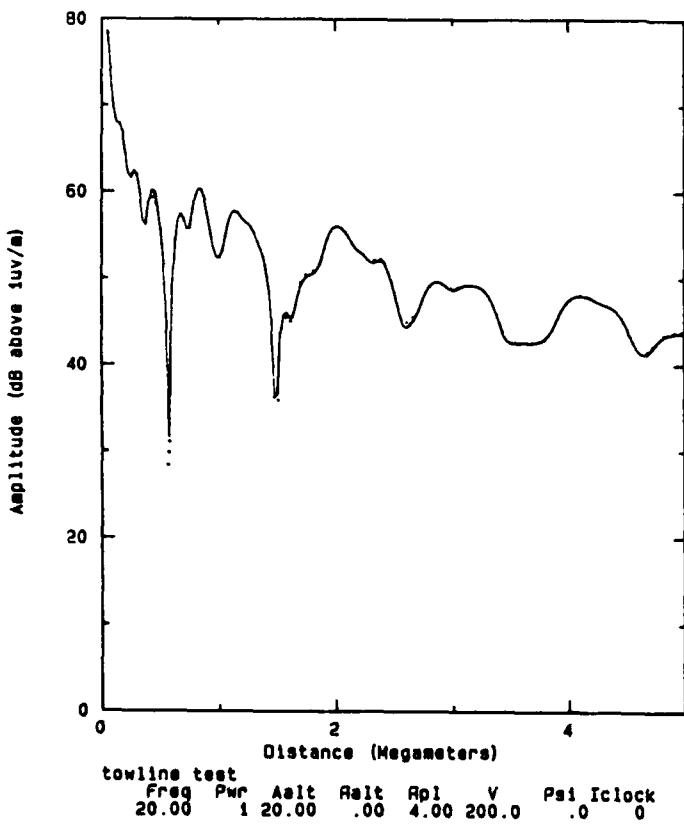
**Figure 3.** Towline length vs. drogue starting conditions.



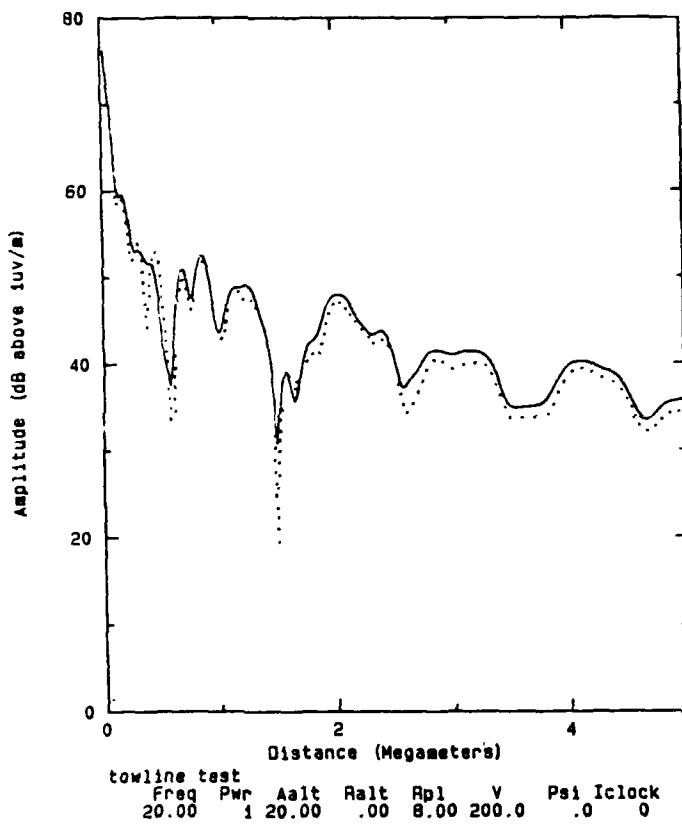
**Figure 4.** Towline length vs. drogue starting conditions.



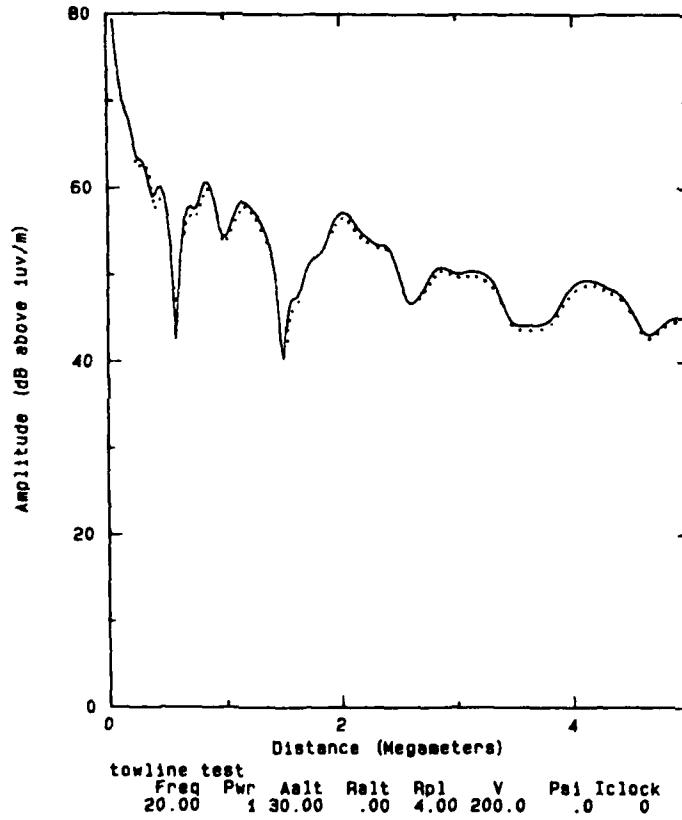
**Figure 5.** Towline length vs. drogue starting conditions.



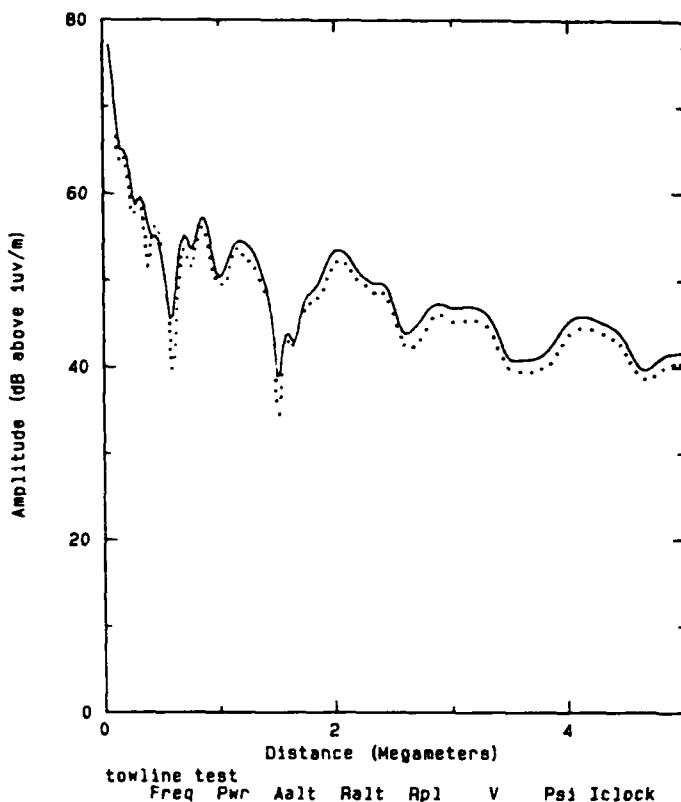
**Figure 6.** EZ field strength comparisons between "TWIRE" (—) and point dipole (· · ·) results for an azimuth of  $90^\circ$ . Point dipole orientation and altitude given by  $\gamma = 17.84^\circ$ ,  $\phi = -58.69^\circ$  and  $z = 12,945$  ft.



**Figure 7.** EZ field strength comparisons between "TWIRE" (—) and point dipole (· · ·) results for an azimuth of 90°. Point dipole orientation and altitude given by  $\gamma = 70.33^\circ$ ,  $\phi = 7.23^\circ$  and  $z = 17,250$  ft.

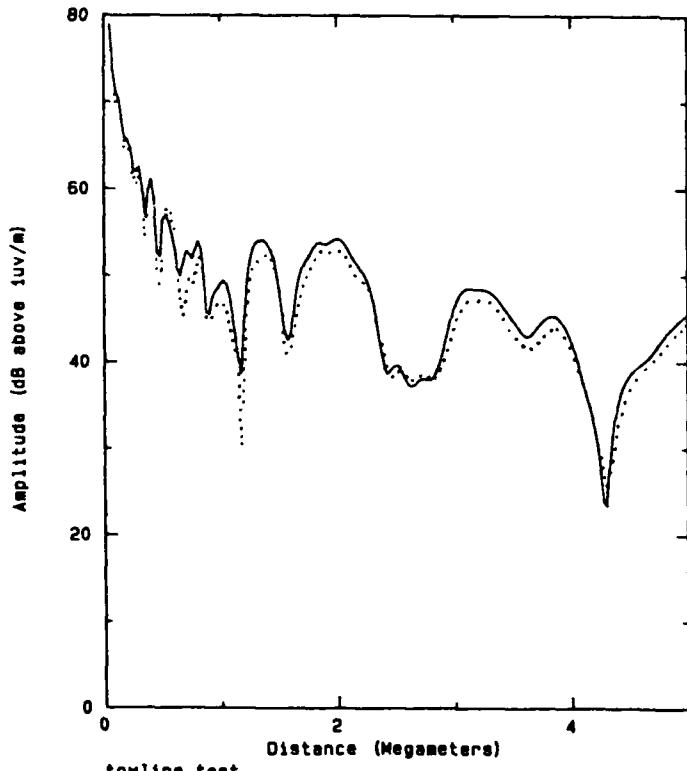


**Figure 8.** EZ field strength comparisons between "TWIRE" (—) and point dipole (· · ·) results for an azimuth of 90°. Point dipole orientation and altitude given by  $\gamma = 19.00^\circ$ ,  $\phi = -47.18^\circ$  and  $z = 22,627$  ft.



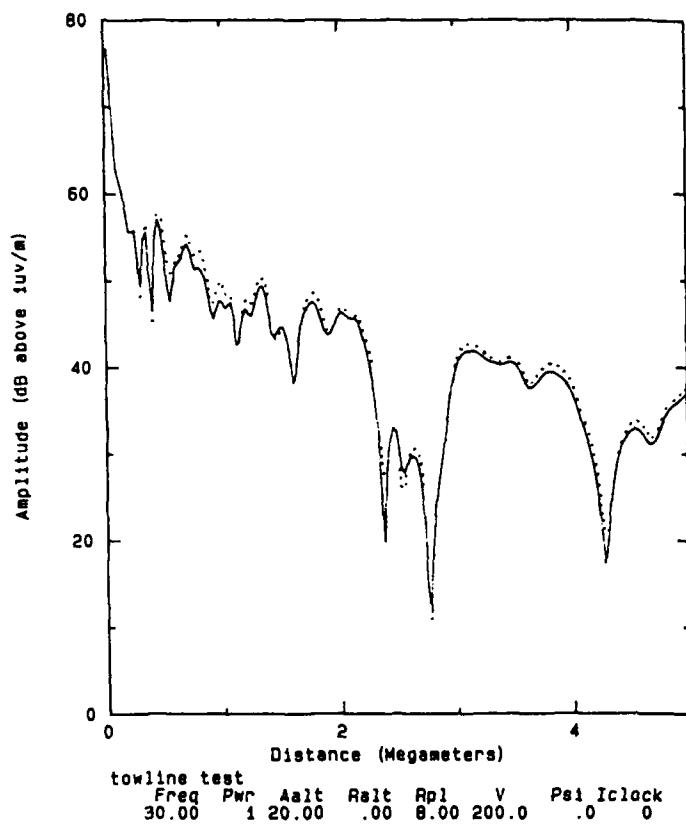
**Figure 9.** EZ field strength comparisons between "TWIRE" (—) and point dipole (· · ·) results for an azimuth of 90°. Point dipole orientation and altitude given by  $\gamma = 55.89^\circ$ ,  $\phi = -3.63^\circ$  and  $z = 26,037$  ft.

towline test  
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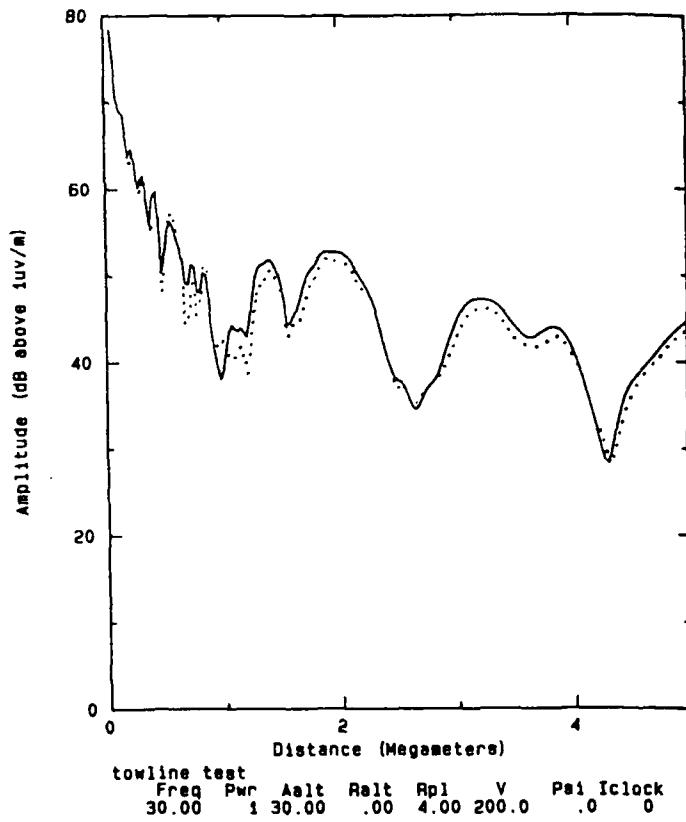


**Figure 10.** EZ field strength comparisons between "TWIRE" (—) and point dipole (· · ·) results for an azimuth of 90°. Point dipole orientation and altitude given by  $\gamma = 38.38^\circ$ ,  $\phi = -29.96^\circ$  and  $z = 16,757$  ft.

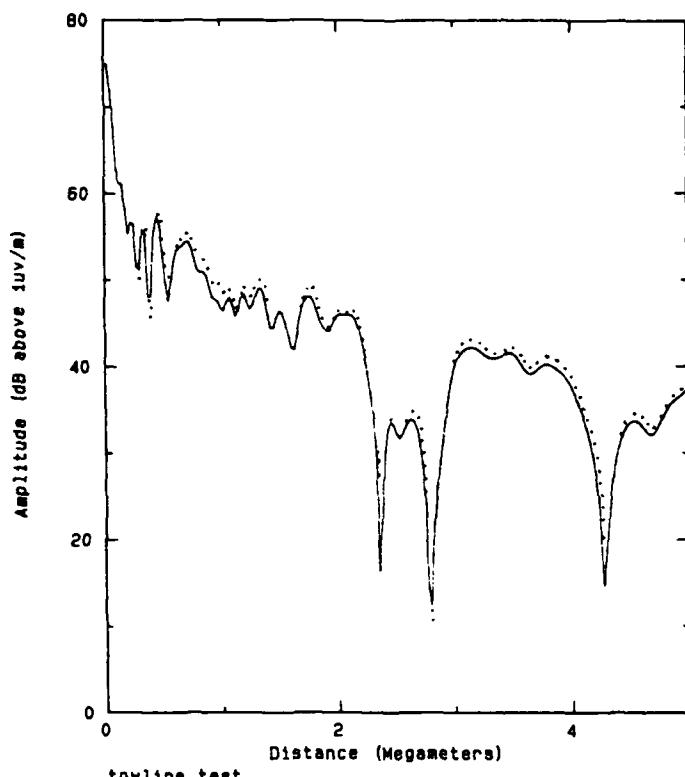
towline test  
 Freq Pwr Aalt Ralt Rpl V Psi Iclock  
 30.00 1 20.00 .00 4.00 200.0 .0 0



**Figure 11.** EZ field strength comparisons between "TWIRE" (—) and point dipole (· · ·) results for an azimuth of 90°. Point dipole orientation and altitude given by  $\gamma = 73.08^\circ$ ,  $\phi = 40.75^\circ$  and  $z = 18,287$  ft.

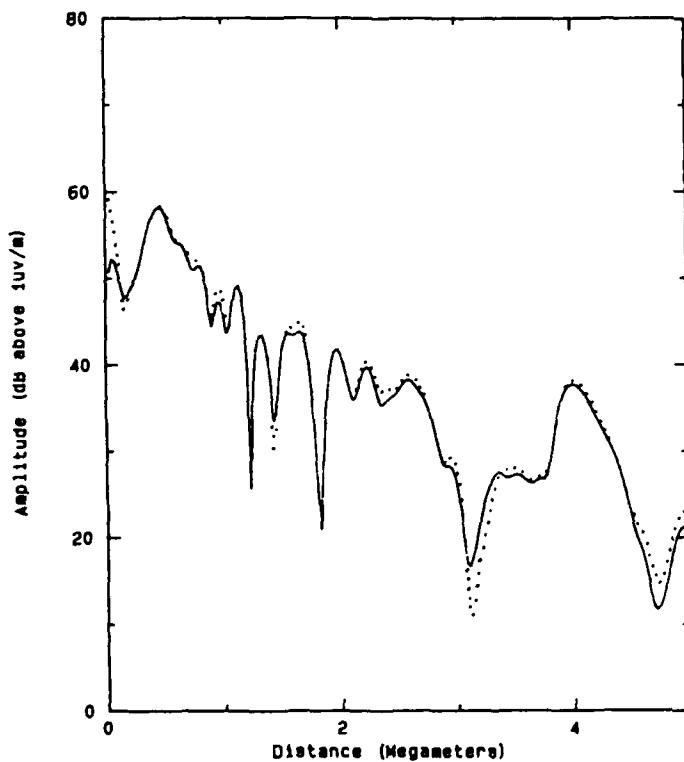


**Figure 12.** EZ field strength comparisons between "TWIRE" (—) and point dipole (· · ·) results for an azimuth of 90°. Point dipole orientation and altitude given by  $\gamma = 36.40^\circ$ ,  $\phi = -21.89^\circ$  and  $z = 26,294$  ft.



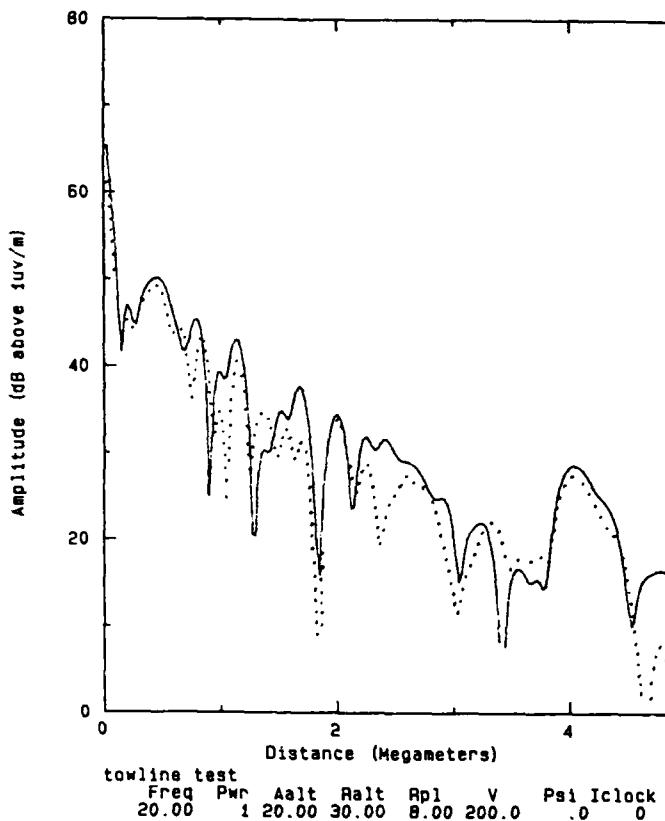
**Figure 13.** EZ field strength comparisons between "TWIRE" (—) and point dipole (· · ·) results for an azimuth of 90°. Point dipole orientation and altitude given by  $\gamma = 69.96^\circ$ ,  $\phi = 42.40^\circ$  and  $z = 27,959$  ft.

towline test  
 Freq Pwr Aalt Ralt Ap1 V Psi Iclock  
 30.00 1 30.00 .00 8.00 200.0 .0 0

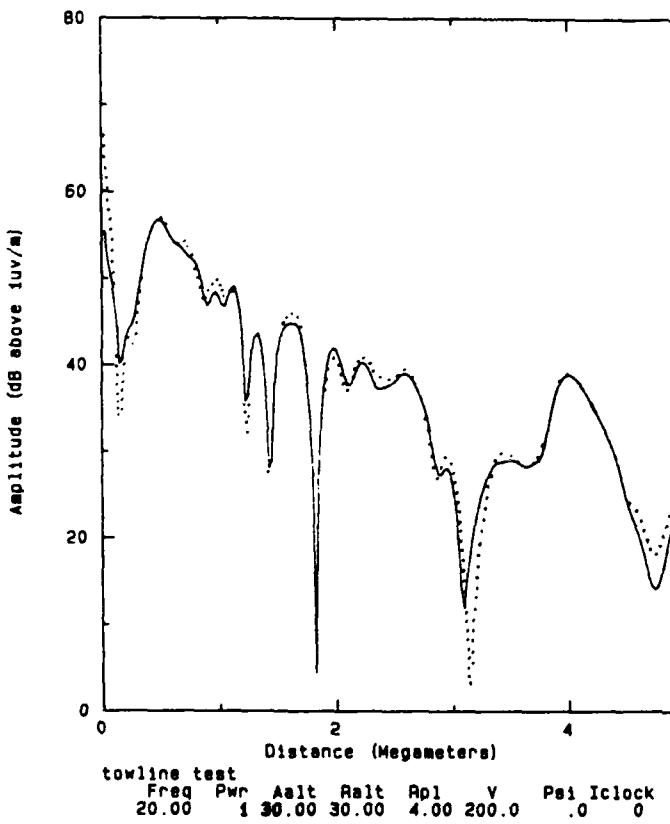


**Figure 14.** EY field strength comparisons between "TWIRE" (—) and point dipole (· · ·) results for an azimuth of 90°. Point dipole orientation and altitude given by  $\gamma = 17.84^\circ$ ,  $\phi = -58.69^\circ$  and  $z = 12,495$  ft.

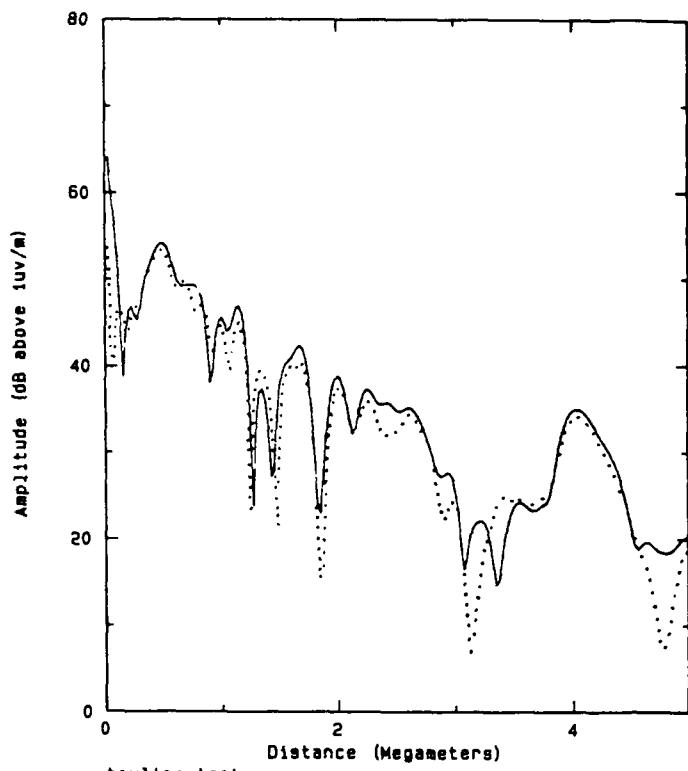
towline test  
 Freq Pwr Aalt Ralt Ap1 V Psi Iclock  
 20.00 1 20.00 30.00 4.00 200.0 .0 0



**Figure 15.** EY field strength comparisons between "TWIRE" (—) and point dipole (· · ·) results for an azimuth of 90°. Point dipole orientation and altitude given by  $\gamma = 70.33^\circ$ ,  $\phi = 7.23^\circ$  and  $z = 17,250$  ft.

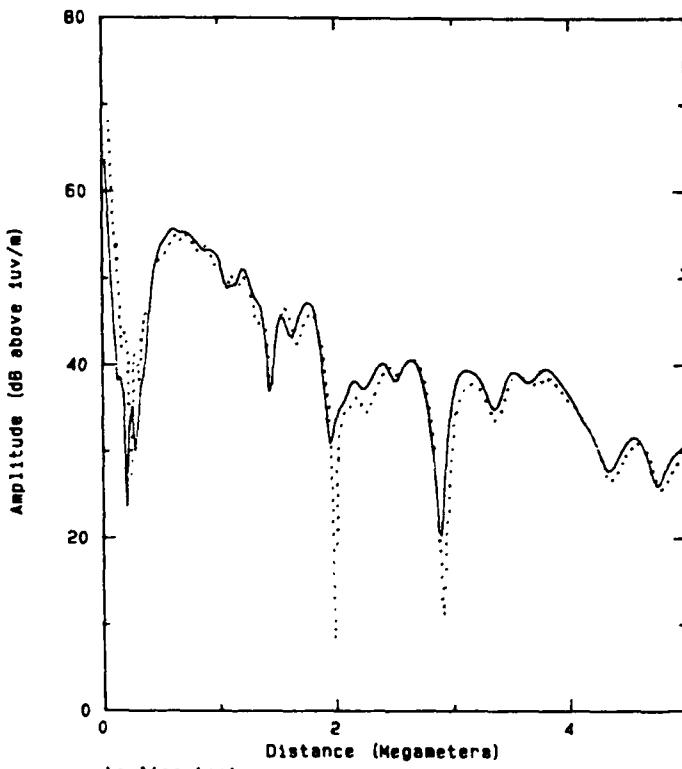


**Figure 16.** EY field strength comparisons between "TWIRE" (—) and point dipole (· · ·) results for an azimuth of 90°. Point dipole orientation and altitude given by  $\gamma = 19.00^\circ$ ,  $\phi = -47.18^\circ$  and  $z = 22,627$  ft.



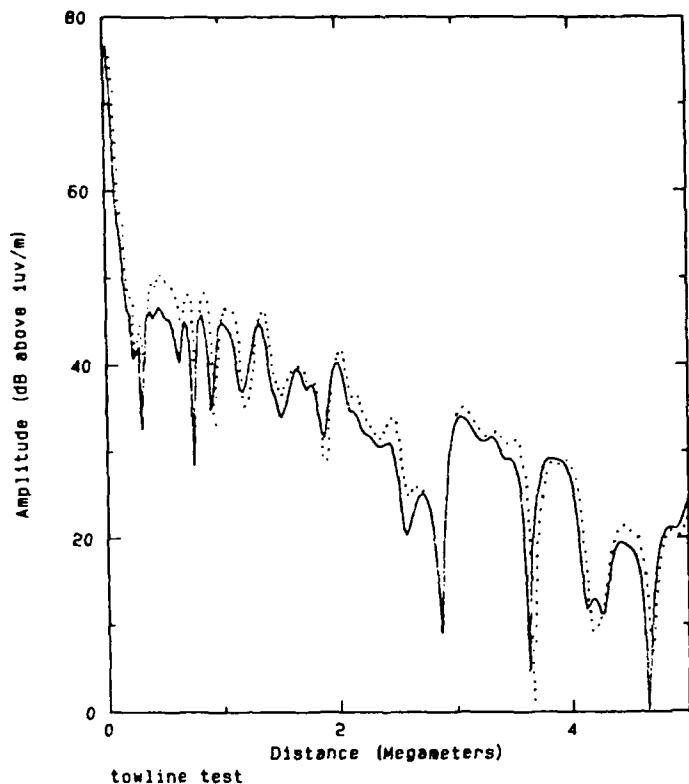
towline test  
 Freq Pwr Aalt Ralt Rpl V Psi Iclock  
 20.00 1 30.00 30.00 8.00 200.0 .0 0

**Figure 17.** EY field strength comparisons between "TWIRE" (—) and point dipole (· · ·) results for an azimuth of 90°. Point dipole orientation and altitude given by  $\gamma = 55.89^\circ$ ,  $\phi = -3.63^\circ$  and  $z = 26,037$  ft.

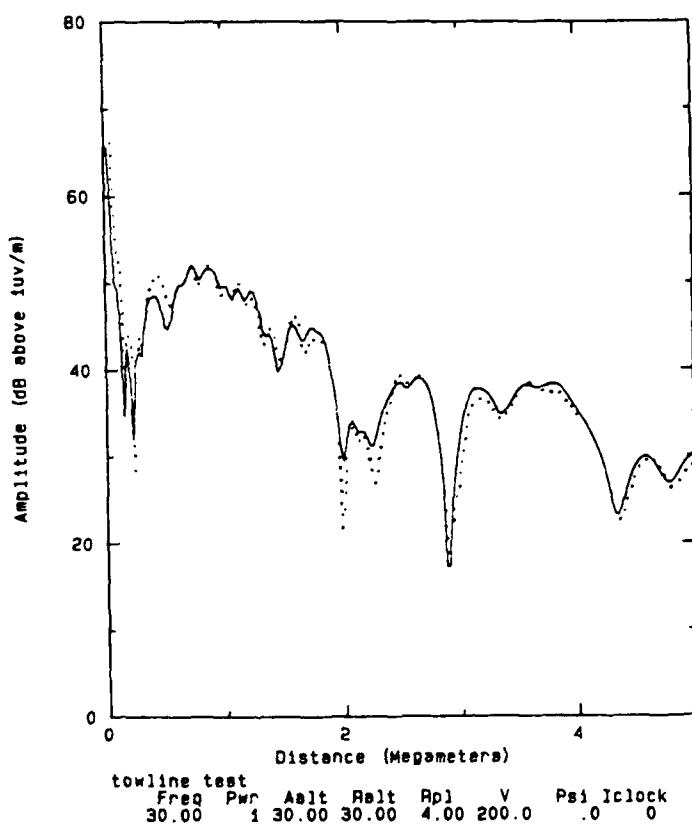


towline test  
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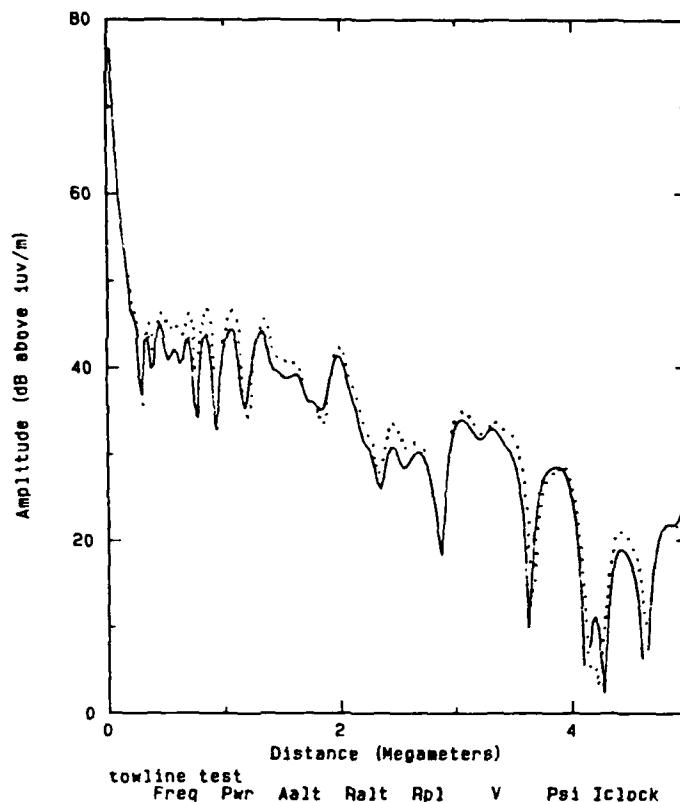
**Figure 18.** EY field strength comparisons between "TWIRE" (—) and point dipole (· · ·) results for an azimuth of 90°. Point dipole orientation and altitude given by  $\gamma = 38.38^\circ$ ,  $\phi = -29.96^\circ$  and  $z = 16,757$  ft.



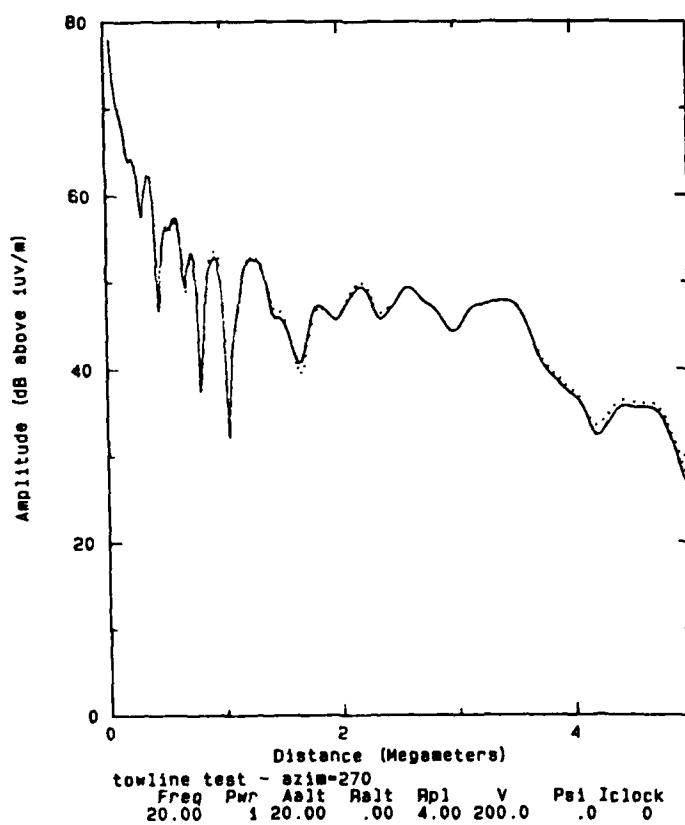
**Figure 19.** EY field strength comparisons between "TWIRE" (—) and point dipole (· · ·) results for an azimuth of 90°. Point dipole orientation and altitude given by  $\gamma = 73.08^\circ$ ,  $\phi = 40.75^\circ$  and  $z = 18,287$  ft.



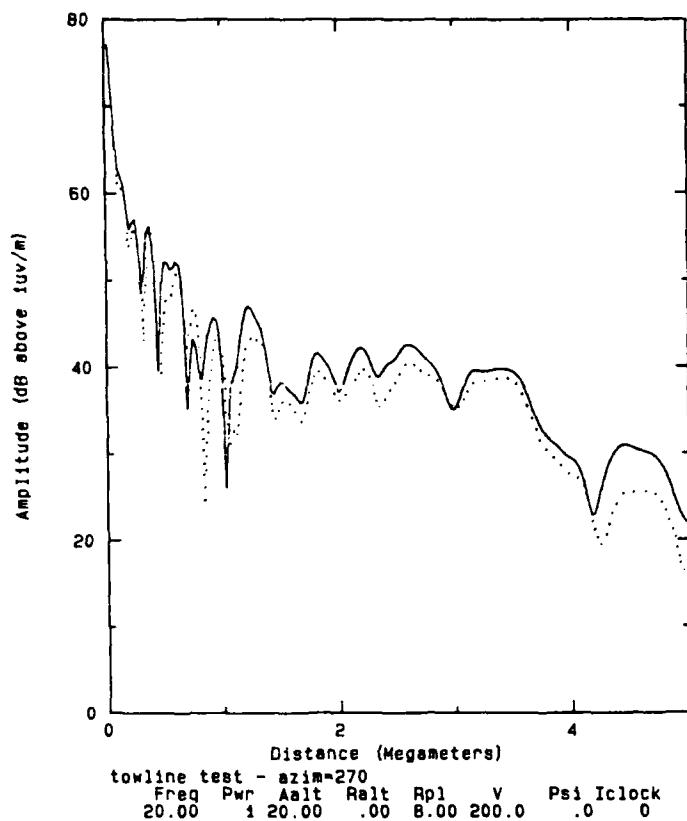
**Figure 20.** EY field strength comparisons between "TWIRE" (—) and point dipole (· · ·) results for an azimuth of 90°. Point dipole orientation and altitude given by  $\gamma = 36.40^\circ$ ,  $\phi = -21.89^\circ$  and  $z = 26,294$  ft.



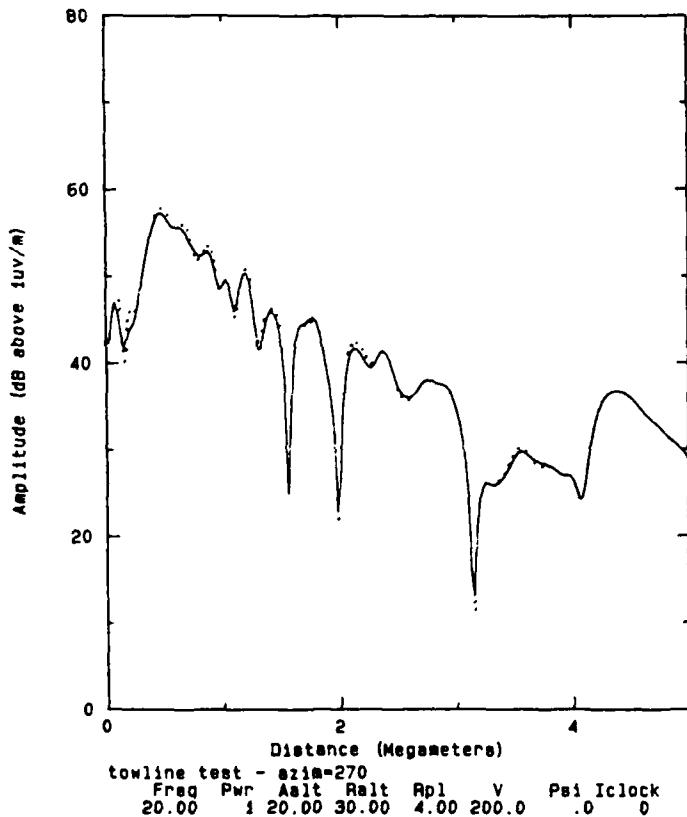
**Figure 21.** EY field strength comparisons between "TWIRE" (—) and point dipole (· · ·) results for an azimuth of  $90^\circ$ . Point dipole orientation and altitude given by  $\gamma = 69.96^\circ$ ,  $\phi = 42.40^\circ$  and  $z = 27,959$  ft.



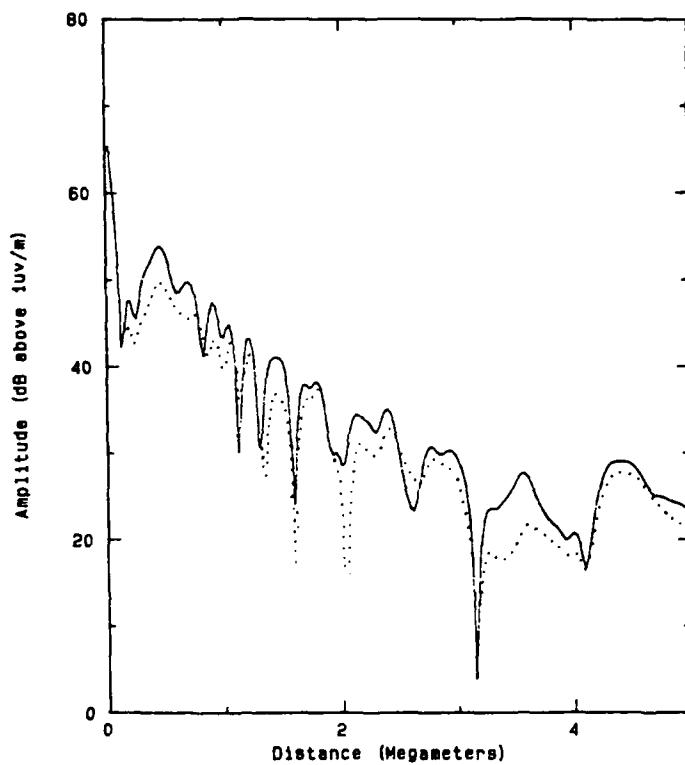
**Figure 22.** EZ field strength comparisons between "TWIRE" (—) and point dipole (· · ·) results for an azimuth of  $270^\circ$ . Point dipole orientation and altitude given by  $\gamma = 17.84^\circ$ ,  $\phi = -58.69^\circ$  and  $z = 12,945$  ft.



**Figure 23.** EZ field strength comparisons between "TWIRE" (—) and point dipole (· · ·) results for an azimuth of  $270^\circ$ . Point dipole orientation and altitude given by  $\gamma = 70.33^\circ$ ,  $\phi = 7.23^\circ$  and  $z = 17,250$  ft.

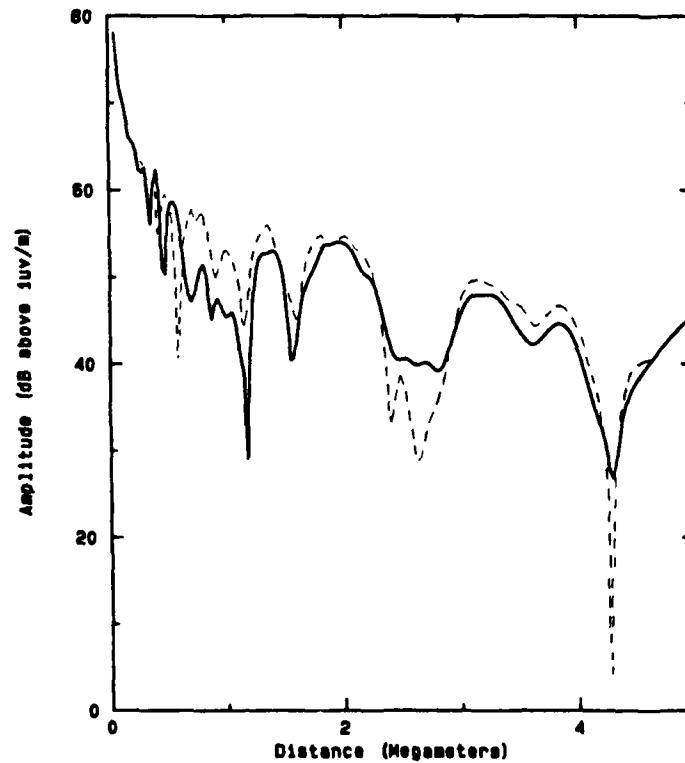


**Figure 24.** EY field strength comparisons between "TWIRE" (—) and point dipole (· · ·) results for an azimuth of  $270^\circ$ . Point dipole orientation and altitude given by  $\gamma = 17.84^\circ$ ,  $\phi = -58.69^\circ$  and  $z = 12,945$  ft.



**Figure 25.** EY field strength comparisons between "TWIRE" (—) and point dipole (· · ·) results for an azimuth of  $270^\circ$ . Point dipole orientation and altitude given by  $\gamma = 70.33^\circ$ ,  $\phi = 7.23^\circ$  and  $z = 17,250$  ft.

towline test - azim=270  
 Freq Pwr Alt Ralt Ap1 V Psi Iclock  
 20.00 1 20.00 30.00 8.00 200.0 .0 0



**Figure 26.** EZ field strengths calculated using "TWIRE" for azimuths of  $90^\circ$  (—) and  $270^\circ$  (---).

towline test  
 Freq Pwr Alt Ralt Ap1 V Psi Iclock  
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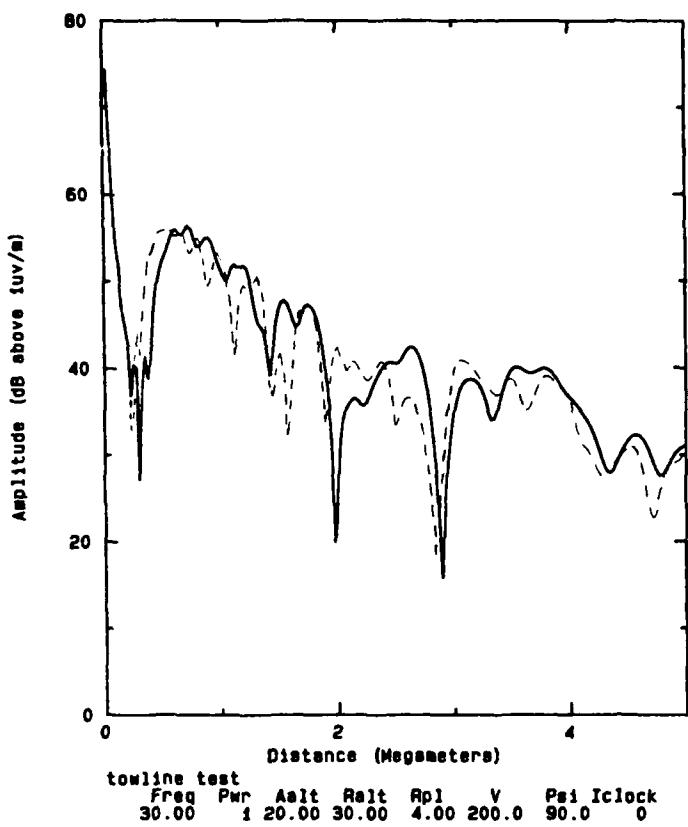


Figure 27. EY field strengths calculated using "TWIRE" for azimuths of 90° (—) and 270° (---).

towline test  
 Freq Pwr Aalt Ralt Rpl V Psi Iclock  
 30.00 1 20.00 30.00 4.00 200.0 90.0 0

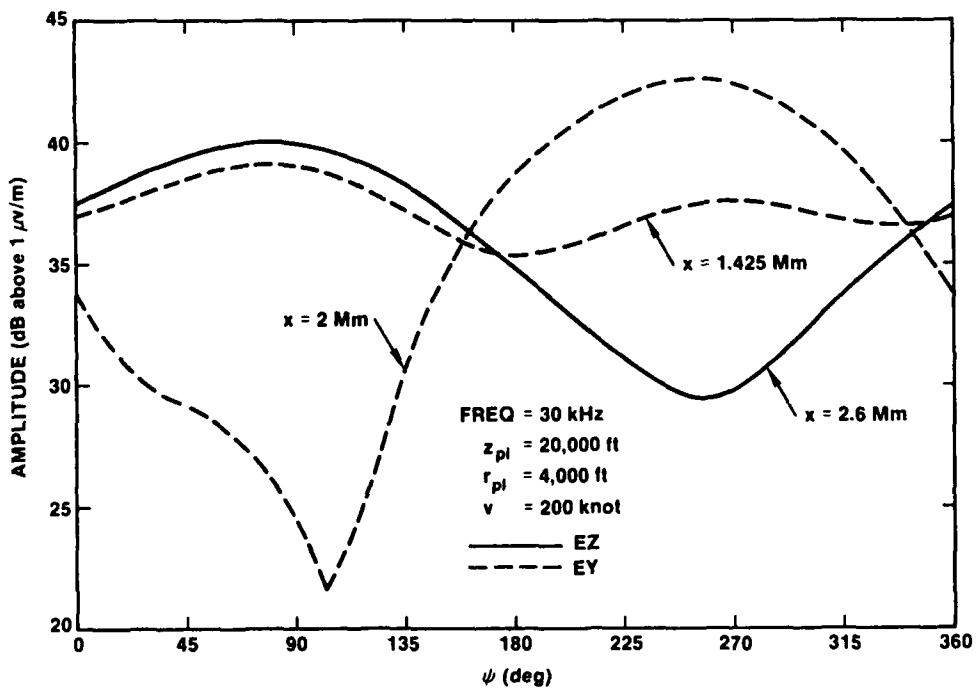
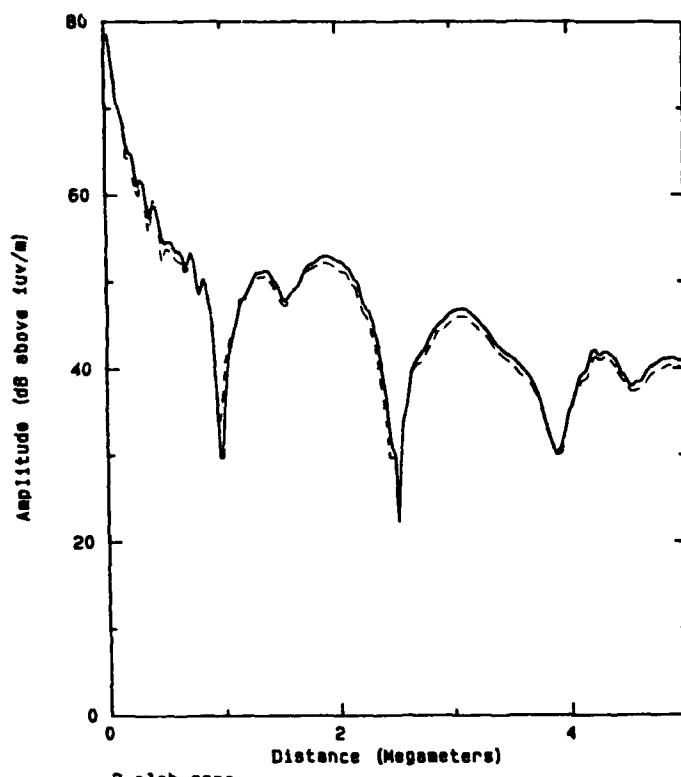
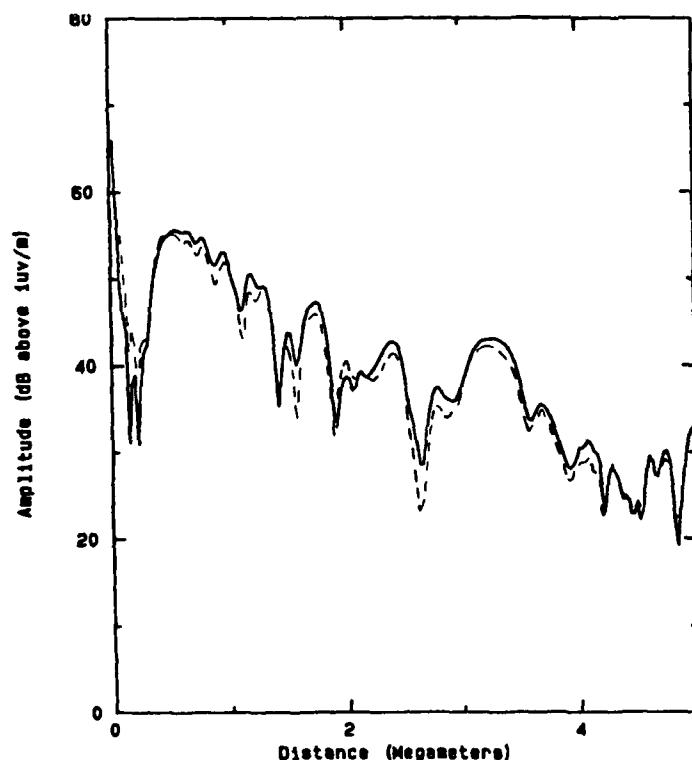


Figure 28. Rotational dependence of EZ and EY field strengths calculated using "TWIRE".



**Figure 29.** EZ field strength comparisons between "TWIRE" (—) and point dipole (---) results for a laterally inhomogeneous guide.

3 slab case  
 Freq Pwr Aalt Ralt Rpl V Psi Iclock  
 30.00 1 20.00 30.00 4.00 200.0 180.0 0



**Figure 30.** EY field strength comparisons between "TWIRE" (—) and point dipole (---) results for a laterally inhomogeneous guide.

3 slab case  
 Freq Pwr Aalt Ralt Rpl V Psi Iclock  
 30.00 1 20.00 30.00 4.00 200.0 180.0 0

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**APPENDIX A—PROGRAM LISTING OF “TWIRE”**

```

c      twire: a program assembled from fastmc(Ferguson and Snyder-NOSC TD
c      400, Nov. 1980), from a towline configuration program(Huang-NADC AM
c      6849, June 1969) and from a radiation resistance program(Pappert-
c      NOSC TR 1112, June 1986)
c
c      parameter (maxmds=30,nstore=(maxmds*(maxmds+3))*2+4)
c      parameter (maxsgs=50)
c
c      implicit real*8 (a-h,o-z)
c      common/mc inpt/xtra(3,maxmds),temp(maxmds),freq,omega,waveno,mik,
c      $      alpha,ak,ak13,ka13,ka23,ngsq,nthsq,sum0,aconst,econst
c      common/mc stor/a(maxmds,maxmds),fofr(maxmds),s(maxmds),tp(maxmds),
c      $      xval,sigma,epsr,nrmode,nrslab
c      common/mc plot/dmin,dmax,dtic,ramin,ramax,ratic,
c      $      ampmmin,ampmax,amptic,phsmin,phsmax,phstic,
c      $      plotid,bumpid,iopt,frq,power,rcomp,
c      $      incl,theta,dst,
c      $      talt,al,aalt,ralt,ident,nrpts,sizex,sizey,cdate(3),
c      $      ctime(2),nrcrvs,nrplts,nrcurv,naplot,npplot,npdiff,npprint
c      common sumout(501),xy(501),amp(501),phs(501),
c      $      hgt(3,maxmds),hgr(3,maxmds)
c      dimension store(nstore),dist(20),idummy(8)
c      complex *16 solsav
c      common/com01/antlen(maxsgs),antrad(maxsgs),antalt(maxsgs),
c      $      antang(maxsgs),npts
c      common/com08/solsav(maxmds,maxsgs)
c      equivalence (store,a)
c      integer rcomp,totape,ctime,cdate
c      character* 4 label,ident
c      character*40 fname,profil,blank
c      character*80 bcd,plotid,bumpid
c      real*4 xy,amp,phs,dmin,dmax,dtic,ramin,ramax,ratic,dist,dst,
c      $      ampmmin,ampmax,amptic,phsmin,phsmax,phstic,
c      $      sizex,sizey,frq,al,talt,aalt,ralt,incl,theta,
c      $      tlong,tlat,rbear,power
c      real*8 ka13,ka23,nthsq
c      complex* 8 sumout
c      complex*16 tp,a,s,fofr,xtra,temp,hgt,hgr,mi,
c      $      mik,ngsq,tmp1,tmp2,tmp3,tmp4,ratio(4),xtra0(maxmds)
c
c      rcomp                  received component, -1 is z, -2 is y
c      power                  radiated power in kw
c      talt                   platform altitude in km
c      al                     antenna length as percentage of wavelength
c      incl,theta              orientation of transmitter antenna
c      topht                  height of the bottom of the ionosphere in km
c      naplot                 amplitude plot flag
c      ampmmin,ampmax,ampinc amplitude plot range and tic interval in db
c      npplot                 phase plot flag
c      phsmin,phsmax,phsinc phase plot range and tic interval in degrees
c      sizex,sizey             axis lengths in inches
c      nrcurv                number of curves per graph, max of 4
c      npprint                printout flag
c      -0                     none
c      -1                     amp and phs only

```

```

c      -2          rfacmset cards and mode constants
c      -3          conversion coefficients and relative excitation
c      -4          slab integrals
c
c      c iopt=1          fields vs distance
c
c      c      ralt          receiver altitude in km
c      c      npdiff         phase difference plot flag
c      c      nrpts1         number of points to output, max of 501
c      c      dmin,dmax,dtic  distance range and tic interval in mm
c      c      totape          output flag, -1 writes to logical unit 2
c      c      tlong,tlat      transmitter location in degrees west,north
c      c      rbear           path bearing in degrees east of north
c
c      c      note: tlong,tlat,rbear are for totape=1 output only
c
c      c iopt=2          fields vs altitude
c
c      c      ramin,ramax,ratic  receiver altitude range in km
c      c      dist,nrd          receiver distances in mm, number of distances
c
c
c      namelist/datum/ iopt,rcomp,al,incl,theta,talt,ralt,topht,
c      $      naplot,npplot,npdiff,nprint,nrcurv,sizex,sizey,
c      $      ampmax,ampmin,amptic,phsmax,phsmin,phstic,
c      $      dmax,dmin,dtic,tlong,tlat,rbear,power,totape,nrpts1,
c      $      ramin,ramax,ratic,dist,nrd,nrpts2
c
c      data label/'zyx ',nflag/0/,idummy/8*0/,
c      $      epsln0/8.85434d-12/,dtr/.01745329252d0/,
c      $      topht/90.d0/,
c      $      tlong,tlat,rbear/0.,0.,0./,totape/0.,
c      $      dist/20*0./,nrd/0.,
c      $      nrpts1/501/,nrpts2/51/,
c      $      blank/
c      data mi/(0.d0,-1.d0)/
c
c      c      unit      use
c      c      1      primary input
c      c      2      totape=1 output
c      c      3      temporary storage of mc data
c      c      4      alternate input of data for a single radial
c
c
c      bumpid(1:4)=' '
c
c      print 2000
c      read 2001, fname
c      lunit1=1
c      open(unit=1,file=fname,status='old')
c      open(unit=3,status='scratch',form='unformatted')
c
c      get date and time for plot identification
c      call date(cdate)
c      call time(ctime)

```

```

c      print 1004,cdate,ctime
c
c      get control card
10    continue
c      print 2002
      read(lunit1,1002,end=998) bcd
      print 1003,bcd
      lunit4=lunit1
c
      if(bcd(1:4) .eq. 'name' .or. bcd(1:4) .eq. 'NAME') then
c          print 2003
c          read namelist
          read(lunit1,datum)
          print datum
          idummy(3)=int(al+.5)
          if(naplot+npplot+npdiff .eq. 3) then
              print *, 'NAPLOT,NPPLOT,NPDIFF can not all be 1'
              go to 10
          endif
          if(phsmin .eq. 0. .or. phsmax .eq. 0.) then
              print *, 'PHSMIN or PHSMAX is zero'
              go to 10
          end if
          if(nrcurv .gt. 4) then
              print *, 'NRCURV .gt. 4'
              go to 10
          end if
          if(sizey .gt. 9.) then
              print *, 'SIZEY .gt. 9'
              go to 10
          end if
          if(iopt .eq. 1) then
              if(nrpts1 .gt. 501) then
                  print *, 'NRPTS1 .gt. 501'
                  go to 10
              end if
              nrpts=nrpts1
          else
              nrpts=nrpts2
          end if
          go to 10
      end if
c
      if(bcd(1:4) .eq. 'bump' .or. bcd(1:4) .eq. 'BUMP') then
c          store bump id card
          bumpid=bcd
          go to 10
      end if
c
      if(bcd(1:4) .eq. 'outp' .or. bcd(1:4) .eq. 'OUTP') then
          j=7
          do while (bcd(j:j) .eq. ' ')
              if(j .eq. 80) then
                  print *, 'Output file name not found'
                  go to 10

```

```

        end if
        j=j+1
    end do
    fname=bcd(j:)
    open(unit=2,file=fname,status='new',form='unformatted')
    go to 10
end if
c
if(bcd(1:4) .eq. 'inpu' .or. bcd(1:4) .eq. 'INPU') then
    j=7
    do while (bcd(j:j) .eq. ' ')
        if(j .eq. 80) then
            print *, 'Input file name not found'
            go to 10
        end if
        j=j+1
    end do
    fname=bcd(j:)
    open(unit=4,file=fname,status='old')
    lunit4=4
    read(lunit4,1002) bcd
    print 1003,bcd
    go to 19
end if
c
if(bcd(1:4) .eq. 'clos' .or. bcd(1:4) .eq. 'CLOS') then
    if(bcd(7:7) .eq. 'o' .or. bcd(7:7) .eq. 'O') then
        close(unit=2)
    else
        close(unit=4)
        lunit4=lunit1
    end if
    go to 10
end if
c
19  if(bcd(1:4) .eq. 'sw ' .or. bcd(1:4) .eq. 'SW ') then
c      get xmtr and profile parameters
      read(bcd,1018) tlong,tlat,rbear,profil
      go to 20
end if
c
if(bcd(1:4) .eq. 'ipsq' .or. bcd(1:4) .eq. 'IPSQ') then
c      get xmtr and profile parameters
      read(bcd,1018) tlong,tlat,rbear,profil
      go to 20
end if
c
if(bcd(1:4) .eq. 'data' .or. bcd(1:4) .eq. 'DATA') then
    profil=blank
    rbear=720.
    go to 20
end if
c
if(bcd(1:4) .eq. 'star' .or. bcd(1:4) .eq. 'STAR') go to 30
c

```

```

if(bcd(1:4) .eq. 'quit' .or. bcd(1:4) .eq. 'QUIT') go to 998
c
      print *, 'Error in control card'
      go to 10
c
c      read propagation path data
20      read(lunit4,1002) plotid
      if(rbear .ne. 720.) then
          j=1
          do while (plotid(j:j+12) .ne. '          ')
              if(j .eq. 67) then
                  print *, 'Plot identification is too long to append bearing'
                  go to 22
              end if
              j=j+1
          end do
          write(plotid(j:j+12),1021) rbear
      end if
22      print 1003,plotid
      nrmode=maxmds
      nrslab=0
      rho=-1.
      th=0.
      nthsq=1.+alpha*tophth
      rewind 3
23      read(lunit4,1002) bcd
      read(bcd,1020) rr,ff,aa,cc,bb,ss,ee
      if(rr .ne. 40. .and. ss .eq. 0.) go to 23
      xval=rr*1000.
      if(nrslab .gt. 0) write(3) store
c
      if(rr .lt. 40.) then
          nrslab=nrslab+1
          nm=0
          bb=bb*10000.
          if(bcd(71:71) .eq. 't' .or. bcd(71:71) .eq. 'T')
$          read(bcd,1028) th
          if(nprint .ge. 1) print 1022,nrslab,rr,ff,aa,cc,bb,ss,ee,th
          if(nprint .ge. 4) print 1024
          if(rr .eq. 0.) then
c              if(nprint .le. 1) print 1022,nrslab,rr,ff,aa,cc,bb,ss,ee,th
              frq=ff
              freq=ff
              const=682.2408*dsqrt(freq)
              omega=6.283185308d3*freq
              waveno=20.958445d-3*freq
              mik=dcmplx(0.d0,-waveno)
              aconst=-8.686d3*waveno
              econst=20.*dlog10(35.*waveno)
              ak=alpha/waveno
              ak13=dexp(dlog(ak)/3.d0)
              kal3=1.d0/ak13
              ka23=kal3**2
              end if
              if(rho .gt. rr) then

```

```

        print *, 'Rhos are out of order'
        go to 10
    end if
    rho=rr
    sigma=ss
    epsr=ee
    ngsq=dcmplx(epsr,-sigma/(omega*epsln0))
    if(th .gt. 0.) nthsq=1.+alpha*th
24    read(lunit4,1023) indx1,tr1,til,itrm1,tmp1,tmp2
c
        if(indx1 .gt. 0) then
            read(lunit4,1023) indx2,tr2,ti2,itrm2,tmp3,tmp4
            if(nm .eq. maxmds) go to 24
            if(zabs(tmp1) .eq. 0.) go to 24
            if(tr1 .ne. tr2 .or. til .ne. ti2 .or. itrm1 .ne. itrm2) then
                print *, 'Modes are out of order'
                go to 10
            end if
            if(itrm1 .eq. 0) then
                print *, 'Mode conversion flag is missing'
                go to 10
            end if
            nm=nm+1
            if(nprint .ge. 4) then
                print 1025,nm,indx1,tr1,til,itrm1,tmp1,tmp2,
$                                indx2,tr2,ti2,itrm2,tmp3,tmp4
            end if
            tp(nm)=dcmplx(tr1,til)
            s(nm)=zsin(tp(nm)*dtr)
            ratio(2*indx1-1)=tmp1
            ratio(2*indx1 )=tmp2
            ratio(2*indx2-1)=tmp3
            ratio(2*indx2 )=tmp4
            temp(nm)=ratio(4)
c            get vertical excitation factor for printout
            xtra0(nm)=(-2.124292961d0,0.d0)*ratio(1)*s(nm)**2
c            get ey/hy
            if(itrm1 .eq. 1) then
                fofr(nm)=ratio(3)/ratio(1)
            else
                fofr(nm)=ratio(2)/(ratio(3)*ratio(4))
            end if
            if(nrslab .eq. 1) then
c                get hy excitation factor at the transmitter
                xtra(1,nm)=-ratio(1)*s(nm)
                xtra(2,nm)= ratio(3)*ratio(4)
                xtra(3,nm)= ratio(1)
            end if
            go to 24
        else
            if(nprint .gt. 1) print 1027,nm
            nrmode=nm
        end if
c
        if(nprint .gt. 1) then

```

```

c      print mode constants table
c      print 1031
c      do 26 m=1,nrmode
c          sr=dble(s(m))
c          si=dimag(s(m))
c          atten=aconst*si
c          voverc=1.d0/sr
c          wr=dble(xtra0(m))
c          wi=dimag(xtra0(m))
c          wml=econst+10.d0*dlog10(dmax1(wr**2+wi**2,1.d-20))
c          wal=datan2(wi,wr)-1.5707963267949d0
c          print 1032,m,atten,voverc,wml,wal
26      continue
c      end if
c
c      get conversion coefficients
c      call mcstep
c      go to 23
c
c      else
c
c      if(nrslab .le. 1) then
c          print *,'Insufficient number of slabs, ',
c          $           'horizontally homogeneous only'
c      end if
c      end if
c
c      calculate mode sum
30      ident=label(rcomp:rcomp)//'
c          sum0=const*sqrt(power)
c          call tacamo
c          call coord
c          call rpower
c
c          if(iopt .eq. 1) then
c
c              deltatad=(dmax-dmin)/float(nrpts-1)
c              dst=dmin
c              do 31 i=1,nrpts
c                  xy(i)=dst
c                  call mcflds(i,dst,sumout(i),amp(i),phs(i))
31              dst=dst+deltad
c
c              if(totape .gt. 0)
c                  save mode sum
c                  $      write(2) sumout,frq,tlong,tlat,rbear,power,rcomp,incl,theta,
c                  $           talt,ralt,dmin,dmax,idummy,profil
c
c              mode sum output
c              call mcplts
c
c              else
c
c                  deltar=(ramax-ramin)/float(nrpts-1)
c                  do 43 i=1,nrd

```

```

        dst=dist(i)
        ralt=0.
        call mcflds(i,dst,sumout(1),amp(1),phs(1))
        phs1=phs(1)
        cycle=0.
c
        ralt=ramin
        do 42 j=1,nrpts
        call htgain(2,freq,sigma,epsr,alpha,nrmode,tp,dble(ralt),hgr)
        tmp1=(0.d0,0.d0)
        do 41 m=1,nrmode
        do 41 jj=1,npts
        tmp1=tmp1+solsav(m,jj)*hgr(rcomp,m)
        tar=tmp1
        tai=tmp1*mi
        phs2=datan2(tai,tar)*57.2957795d0
        if(dabs(phs1-phs2) .ge. 180.d0) then
          if(phs1 .le. phs2) then
            cycle=cycle-360.d0
          else
            cycle=cycle+360.d0
          end if
        end if
        phs1=phs2
        xy(j)=ralt
        amp(j)=10.*dlog10(tar**2+tai**2)
        phs(j)=phs2+cycle
        sumout(j)=tmp1
42      ralt=ralt+deltar
43      call mcplts
        ralt=0.
        call htgain(1,freq,sigma,epsr,alpha,nrmode,tp,dble(ralt),hgr)
c
        end if
        if(nprint.gt.0) print 1000
        if(lunit4 .eq. 4) then
          read(lunit4,1002,end=49) bcd
          print 1003,bcd
          go to 19
49      close(unit=4)
        end if
        go to 10
c
998    print 1998,nrcrvs,nrplts
        stop
c
1000   format('1')
1002   format(a80)
1003   format(1x,a80)
c1004   format('Additional plot identification: ',3a4,1x,2a4)
1018   format(9x,f7.0,2f6.0,6x,a40)
1020   format(1x,f7.0,3(2x,f8.0),2(2x,e10.0),2(2x,e5.0))
1021   format(' rbear=',f5.1)
1022   format(' Slab ',i2,' R',f7.3,' F',f8.4,' A',f8.3,' C',f8.3,' M',
$   f6.3,' S',1pe10.3,' E',0pf5.1,' T',f5.1)

```

```

1023 format(i1,2f9.0,i1,4e15.0)
1024 format(/11x,' M  ID  THETA''')
1025 format(11x,i2,3x,i1,0p2f10.5,i2,2(1x,1p2e16.8)/
$      16x,      i1,0p2f10.5,i2,2(1x,1p2e16.8))
1026 format(16x,      i1,0p2f10.5,i2,2(1x,1p2e16.8)/
$      16x,      i1,0p2f10.5,i2,2(1x,1p2e16.8))
1027 format('+',80x,' Modes',i3)
1028 format(71x,f5.0)
1031 format(' MODE  ATTEN  V/C      WAIT''S EXC')
1032 format(i4,f8.3,f9.5,2(f10.3,f7.3))
1998 format(' End of job, ',i2,' curves plotted in ',i2,' graphs')
2000 format(' Enter .com file name: ')
2001 format(a40)
2002 format(' Control card: [name input output start quit close] '$)
2003 format(' Enter DATUM: iopt[1] rcomp[1] power[1]/
$      '           incl[0] theta[0] talt[0] ralt[0]/
$      '           dmin[0] dmax[10] dtic[1]/
$      '           tlong[0] tlat[0] rbear[0] totape[0]/
$      '           ampmin[-50] ampmax[70] amptic[10]/
$      '           phsmin[-360] phsmax[360] phstic[90]/
$      '           sizex[5] sizey[6]/
$      '           nrd[0] dist[20*0]/
$      '           ramin[0] ramax[50] ratic[5]/
$      '           nrpts[501] nrpts1[501] nrpts2[51]/
$      '           nrcurv[1] naplot[1] npplot[0] nprint[0]')
      end

```

```

block data
c
parameter (maxmds=30,nstore=(maxmds*(maxmds+3))*2+4)
c
implicit real*8 (a-h,o-z)
common/mc inpt/xtra(3,maxmds),temp(maxmds),freq,omega,waveno,mik,
$      alpha,ak,ak13,ka13,ka23,ngsq,nthsq,sum0,aconst,econst
common/mc plot/dmin,dmax,dtic,ramin,ramax,ratic,
$      ampmin,ampmax,amptic,phsmin,phsmax,phstic,
$      plotid,bumpid,iopt,frq,power,rcomp,
$      incl,theta,dst,
$      talt,al,aalt,ralt,ident,nrpts,sizex,sizey,cdate(3),
$      ctime(2),nrcrvs,nrplts,nrcurv,naplot,npplot,npdiff,nprint
integer rcomp,ctime,cdate
character* 4 ident
character*80 plotid,bumpid
real*8 ka13,ka23,nthsq
complex*16 xtra,temp,mik,ngsq
real*4 dmin,dmax,dtic,ramin,ramax,ratic,dst,
$      ampmin,ampmax,amptic,phsmin,phsmax,phstic,
$      sizex,sizey,frq,al,talt,aalt,ralt,incl,theta,
$      power
c
data iopt/1,
$      alpha/3.14d-04/,
$      rcomp/1.,incl,theta/0.,0./,talt,ralt/0.,0./,
$      power/1./,al/0./,
$      dmin,dmax,dtic/0.,10.,1./,
$      ramin,ramax,ratic/0.,50.,5./,
$      ampmin,ampmax,amptic/-50.,70.,10./,
$      phsmin,phsmax,phstic/-360.,360.,90./,
$      sizex,sizey/5.,6./,
$      nrpts/501.,
$      nrcurv/1.,naplot/1.,npplot/0.,npdiff/0.,nprint/0.,
$      nrcrvs,nrplts/0,0/
c
end

```

```

subroutine coord
c
c      implicit real*8 (a-h,o-z)
c
c      parameter (maxsgs=50)
c
c      real*4 gamma,phi
c      common/com01/antlen(maxsgs),antrad(maxsgs),antalt(maxsgs),
c      $           antang(maxsgs),npts
c      common/com02/cpl,psi,iclock,chicp
c      common/com03/x(maxsgs),y(maxsgs),z(maxsgs)
c      common/com04/xmid(maxsgs),ymid(maxsgs),zmid(maxsgs)
c      common/com05/gamma(maxsgs),phi(maxsgs)
c
c      nsegs=npts-1
c
c      calculate coordinates of ends of segments of the antenna
900  format(2x,' segment',9x,'x',11x,'y',11x,'z')
      do i=1,nsegs+1
        x(i)=antrad(i)*cos(antang(i))
        y(i)=antrad(i)*sin(antang(i))
        z(i)=antalt(i)
      enddo
c
c      Transformation
c      capphi=datan2(y(npts),x(npts))
      do i=1,nsegs+1
        xprime= x(i)*cos(capphi)+y(i)*sin(capphi)
        yprime=-x(i)*sin(capphi)+y(i)*cos(capphi)
        x(i)=xprime
        y(i)=yprime
      enddo
c
      do i=1,nsegs+1
        x(i)=x(i)-x(npts)
        y(i)=y(i)-y(npts)
      enddo
c
c      if airplane is moving in a clockwise orbit (iclock=1) then change y
      if(iclock .eq. 1) then
        do i=1,nsegs+1
          y(i)=-y(i)
        enddo
      endif
c
      cpsi=cos(psi*0.0174533)
      spsi=sin(psi*0.0174533)
      do i=1,nsegs+1
        xpp= x(i)*cpsi+y(i)*spsi
        ypp=-x(i)*spsi+y(i)*cpsi
        x(i)=xpp
        y(i)=ypp
      enddo
c
      z(nsegs+2)=z(nsegs+1)-cpl*sin(chicp*.0174533)

```

```

x(nsegs+2)= -cpl*spsi*cos(chicp*.0174533)
y(nsegs+2)= -cpl*cpsi*cos(chicp*.0174533)
if(iclock .eq. 1) then
  x(nsegs+2)=-x(nsegs+2)
  y(nsegs+2)=-y(nsegs+2)
endif

do i=1,nsegs+1
  if(antlen(i) .le. (antlen(nsegs+1)+cpl)/2. .and.
$    antlen(i+1) .gt. (antlen(nsegs+1)+cpl)/2.)then
    imid=i
    go to 915
  end if
end do
915 print *, 'imid=',imid
c  calculate midpoints of segments of the antenna
do i=1,nsegs+1
  xmid(i)=(x(i+1)+x(i))/2.0
  ymid(i)=(y(i+1)+y(i))/2.0
  zmid(i)=(z(i+1)+z(i))/2.0
end do

c  calculate gamma and phi
c  gamma=inclination angle of antenna from the vertical
c  phi=azimuth
  print *, ' AFTER TRANSFORMATION'
  print 910
910  format(2x,' segment',6x,'xmid',8x,'ymid',8x,'zmid',10x,'gamma',
$          7x,'phi')
  do i=1,nsegs+1
    delx=x(i+1)-x(i)
    dely=y(i+1)-y(i)
    delz=z(i+1)-z(i)
    gamma(i)=atan2(sqrt(delx**2+dely**2),delz)
    phi(i)=atan2(dely,delx)
    print 905,i,xmid(i),ymid(i),zmid(i),
$          gamma(i)*57.29578,phi(i)*57.29578
905  format(' ',4x,i3,6x,5(f10.3,2x))
  enddo
  return
end

```

```

subroutine mcflds(index,dst,sumout,amp,phs)
c
c      calculate mode sum
c
      parameter (maxmds=30,nstore=(maxmds*(maxmds+3))*2+4)
      parameter (maxsgs=50)
c
      implicit real*8 (a-h,o-z)
      real*8 idl
      real*4 gamma,phi
c
      common/com01/antlen(maxsgs),antrad(maxsgs),antalt(maxsgs),
      $           antang(maxsgs),npts
      common/com04/xmid(maxsgs),ymid(maxsgs),zmid(maxsgs)
      common/com05/gamma(maxsgs),phi(maxsgs)
      common/com06/idl(maxsgs)
      common/mc inpt/xtra(3,maxmds),temp(maxmds),freq,omega,waveno,mik,
      $           alpha,skip(7),const0,aconst,econst
      common/mc stor/a(maxmds,maxmds),fofr(maxmds),s(maxmds),tp(maxmds),
      $           xtwo,sigma,epsr,nrmode,nrslab
      common/mc plot/iskipl(12),plotid(20),iskip2(23),rcomp,
      $           incl,theta,iskip3,talt,al,aalt,ralt,
      $           ident,iskip4(14),nprint
      common iskip5(2505),hgt(3,maxmds),hgr(3,maxmds),
      $           soln a(maxmds,maxsgs),soln b(maxmds,maxsgs)
      dimension store(nstore),t(3)
      complex*16 ssav
      dimension ssav(maxmds)
      equivalence (store,a)
      complex*16 a,s,tp,fofr,xtra,temp,solna,solnb,hgt,hgr,
      $           ta,tb,mi,one,mik,mikx
      complex *16 solsav
      common/com08/solsav(maxmds,maxsgs)
      real*4 amp,phs,incl,theta,talt,al,aalt,ralt,dst
      integer rcomp,tcomp,pnmode
      complex* 8 sumout
      complex*16 sum
      character*4 plotid,ident
      data mi/(0.d0,-1.d0)/,one/(1.d0,0.d0)/
c
      const1=2.853d-3*freq**1.5
      sum=0.
      rho=dst*1000.
      numseg=npts-1
      900 format(' i,dst,ant len,rad,alt,ang=',i3,5e12.5)
      905 format(' i,dst,x,y,zmid,gamma,phi,idl=',i3,7e12.5)
c
      if(index .eq. 1) then
         rewind 3
         read(3) store
         do m=1,nrmode
            ssav(m)=s(m)
         enddo
         xone=0.d0
         phs1=0.

```

```

cycle=0.
mikx=mik*xtwo
call htgain(1,freq,sigma,epsr,alpha,nrmode,tp,dble(ralt),hgr)
end if
do i=1,numseg+1
  if(index .eq. 1) then
c
c      antenna orientation factors
t(1)=cos(gamma(i))
t(2)=sin(gamma(i))*sin(phi(i))
t(3)=sin(gamma(i))*cos(phi(i))
c
c      xone is distance of previous slab from the transmitter
c      xtwo is distance of next slab
c
c      get data for first slab
call htgain(1,freq,sigma,epsr,alpha,nrmode,tp,antalt(i),hgt)
do 689 m=1,nrmode
c      hy excitation factor
ta=(0.d0,0.d0)
do 686 tcomp=1,3
686  ta=ta+xtra(tcomp,m)*hgt(tcomp,m)*t(tcomp)
soln a(m,i)=ta
if(rcomp .eq. 1) then
c        ez excitation factor
ta=-s(m)*ta
else
c        ey excitation factor
ta=fofr(m)*ta
end if
soln b(m,i)=ta*hgr(rcomp,m)
689  continue
c
endif
enddo
c
if(dst .eq. 0.) then
  amp=100.d0
  phs=0.
  sumout=amp
  return
end if
c
720  if(rhc .gt. xtwo) then
c
c      end of current slab
mikx=mik*(xtwo-xone)
pnmode=nrmode
do i=1,numseg+1
  do 735 m=1,pnmode
c      get excitation factors at end of slab
  soln a(m,i)=soln a(m,i)*zexp(mikx*(s(m)-one))
735  solsav(m,i)=soln a(m,i)
enddo
xone=xtwo

```

```

c
c      get data for next slab
      read(3) store
      mikx=mik*xtwo
      call htgain(l,freq,sigma,epsr,alpha,nrmode,tp,dble(ralt),hgr)
      do i=1,numseg+1
          do 740 m2=1,nrmode
c      hy excitation factor
          ta=(0.d0,0.d0)
          do 737 m1=1,pnmode
              ta=ta+solsav(m1,i)*a(m1,m2)
              soln a(m2,i)=ta
              if(rcomp .eq. 1) then
c                  ez excitation factor
                  ta=-s(m2)*ta
              else
c                  ey excitation factor
                  ta=fofr(m2)*ta
              end if
              soln b(m2,i)=ta*hgr(rcomp,m2)
740          continue
c
          enddo
          go to 720
c
      else
c
      get sum of modes
      mikx=mik*(rho-xone)
      do i=1,numseg+1
          ta=0.d0
          factor=idl(i)*constl/dsqrt(dabs(dsin((rho-xmid(i))/6.366d3)))
          do 730 m=1,nrmode
              tb=solnb(m,i)*zexp(mikx*(s(m)-one))*zexp(-mik*xmid(i)*ssav(m))
$              *factor
              solsav(m,i)=tb
730          ta=ta+tb
          sum=sum+ta
          enddo
          end if
          sumr=sum
          sumi=mi*sum
          phs2=datan2(sumi,sumr)*57.2957795d0
          if(dabs(phs1-phs2) .ge. 180.d0) then
              if(phs1 .le. phs2) then
                  cycle=cycle-360.d0
              else
                  cycle=cycle+360.d0
              end if
          end if
          phs1=phs2
          sumout=sum
          amp=10.*dlog10(dmax1(1.d-30,sumr**2+sumi**2))
          phs=phs2+cycle
          return

```

```
c
c
1030 format('1',20a4/1x,a1,' component      INCL =',f4.0,
      $           '     THETA =',f5.0,'     PALT =',f5.1,'     AALT =',f5.1,
      $           '     RALT =',f5.1)
1031 format('OSLAB   RHO   MODE   ATTEN   V/C           REL EXC 1'/
      $           1x,i3,f9.3)
1032 format(13x,i3,f8.3,f9.5,2(f10.3,f7.3))
end
```

```

subroutine mcplts
c
c plot mode sum amplitude and relative phase
c
real*8 cpl,psi,v,rpl,zpl,zplane, radius, chicp
common/com02/cpl,psi,iclock,chicp
common/com09/v,rpl,zpl
common/mc plot/dmin,dmax,dtic,ramin,ramax,ratic,
$      ampmin,ampmax,amptic,phsmin,phsmax,phstic,
$      id(20),bumpid(20),iopt,freq,power,rcomp,
$      angl,ang2,dst,talt,
$      al,aalt,ralt,ident,nrpts,sizex,sizey,cdate(3),ctime(2),
$      nrcrvs,nrplts,nrcurv,naplot,npplot,npdiff,nprint
common skip1(1002),xy(501),out1(501),out2(501),phil(501),up(501)
dimension xl(2),yl(2),ul(2),label(7,5),iplb11(13),iplb12(13)
integer bumpid,cdate,ctime,rcomp,headng(13)
logical up,ul,nframe,pflag
character* 4 ident
character*28 hlabel(5)
character*52 hhead,blank,plb11,plb12
character*80 plotid,saveid
character*80 bumpch
equivalence (label,hlabel),(heading,hhead),(id,plotid),
$      (iplb11,plb11),(iplb12,plb12)
equivalence (bumpch,bumpid)
data nframe/.true./
data jopt/0/
data xl/-1.1,-0.1/,ul/2*.false./
data hhead/'      Freq  Pwr  Aalt  Ralt  Rpl      V      Psi  Iclock      '/
data blank/'
data hlabel/
$      ' Amplitude (dB above luv/m)  ','  Relative phase (Degrees)  ',
$      '  Phase-phasel (Degrees)  ','  Distance (Megameters)  ',
$      '  Altitude (kilometers)  '/
c
c convert plane altitude and plane radius from ft to km
zplane=zpl*1.0d-3
radius=rpl*1.0d-3
c
c convert receiver altitude from km to kft
ral=ralt/0.3048
if(nprint .gt. 0) then
  if(iopt .eq. 1) then
    print 1001,ident,ralt
  else
    print 1003,ident,dst
  end if
  if(out1(1) .ge. 100.) out1(1)=99.99
  nl=nrpts/4+1
  do 19 il=1,nl
19  print 1011,(xy(i),out1(i),out2(i),i=il,nrpts,nl)
end if
c
if(naplot+npplot+npdiff .eq. 0) return
c
if(jopt .ne. iopt) then

```

```

        jopt=iopt
        ndata=0
        line=0
    end if
    ndata=ndata+1
    line=line+1
    if(ndata .eq. 1) then
        if(.not. nframe) then
            call pltend
            line=0
        end if
        nframe=.true.
        do 1 i=1,nrpts
1       phil(i)=out2(i)
    end if
    if(iopt .eq. 1) then
        xmin=dmin
        xmax=dmax
        xtic=dtic
    else
        ymin=ramin
        ymax=ramax
        ytic=ratic
    end if
c
    if(naplot .eq. 1) then
        nplot=1
        amax=ampmax
        amin=ampmin
        atic=amptic
        do 29 i=1,nrpts
        if(outl(i) .le. amax) then
            if(outl(i) .ge. amin) then
                up(i)=.false.
            else
                up(i)=.true.
                outl(i)=amin
            end if
        else
            up(i)=.true.
            outl(i)=amax
        end if
29      continue
        if(iopt .eq. 1) then
            ymax=amax
            ymin=amin
            ytic=atic
        else
            xmax=amax
            xmin=amin
            xtic=atic
        end if
        go to 100
    end if
c

```

```

30    if(npplot .eq. 1) then
      nplot=2
      fk=0.
      do 39 i=1,nrpts
          out1(i)=out2(i)+fk
          up(i)=.false.
35    if(outl(i) .ge. phsmin) then
        if(outl(i) .le. phsmax) go to 39
        fk=fk-phsmax
        outl(i)=outl(i)-phsmax
      else
        fk=fk-phsmin
        outl(i)=outl(i)-phsmin
      end if
      up(i)=.true.
      go to 35
39    continue
      if(iopt .eq. 1) then
        ymax=phsmax
        ymin=phsmin
        ytic=phstic
      else
        xmax=phsmax
        xmin=phsmin
        xtic=phstic
      end if
      go to 100
    end if
c
40    if(npdiff .eq. 1 .and. iopt .eq. 1 .and. ndata .gt. 1) then
      nplot=3
      fk=0.
      do 49 i=1,nrpts
          outl(i)=out2(i)-phil(i)+fk
          up(i)=.false.
45    if(outl(i) .ge. phsmin) then
        if(outl(i) .le. phsmax) go to 49
        fk=fk-phsmax
        outl(i)=outl(i)-phsmax
      else
        fk=fk-phsmin
        outl(i)=outl(i)-phsmin
      end if
      up(i)=.true.
      go to 45
49    continue
      if(iopt .eq. 1) then
        ymax=phsmax
        ymin=phsmin
        ytic=phstic
      else
        xmax=phsmax
        xmin=phsmin
        xtic=phstic
      end if

```

```

        go to 100
    end if
c
50    if(line .eq. nrcurv) then
        call pltend
        nframe=.true.
        line=0
    else
        call plt off
        saveid=plotid
        yp0=yp
    end if
    return
c
100   ipwr=power
    iang1=ang1
    iang2=ang2
    if(line .eq. 1) then
        if(nframe) then
            call pltbgn
            nrplts=nrplts+1
            xp=0.
            yp=0.
            call symbol(xp,yp,.1,'FASTMC',0.,6)
            xp=xp+0.7
            call number(xp,yp,.1,float(nrplts),0.,-1)
            xp=xp+1.0
            call symbol(xp,yp,.1,cdate,0.,9)
            xp=xp+1.0
            call symbol(xp,yp,.1,ctime,0.,8)
            call plot(1.1,0.8+0.45*nrcurv,-3)
            nframe=.false.
        end if
        call bordr2(sizex,xmin,xmax,xtic,2.*xtic,-1,
                   sizey,ymin,ymax,ytic,2.*ytic,-1)
    $    if(iopt .eq. 1) then
        xp=-.7
        yp= .5*(sizey-2.8)
        call symbol(xp,yp,.1,label(1,nplot),90.,28)
        xp= .5*(sizex-2.8)
        yp=-.4
        call symbol(xp,yp,.1,label( 1,4 ), 0.,28)
    else
        xp=-.7
        yp= .5*(sizey-2.8)
        call symbol(xp,yp,.1,label( 1,5 ),90.,28)
        xp= .5*(sizex-2.8)
        yp=-.4
        call symbol(xp,yp,.1,label(1,nplot), 0.,28)
    end if
    xp=0.
    yp=-.6
    if(bumpch(1:4) .ne. '      ') then
        call symbol(xp,yp,.1,bumpid(1),0.,4)
        xp=xp+0.5

```

```

        call symbol(xp,yp,.1,bumpid(2),0.,68)
        xp=0.
        yp=yp-.15
    end if
    call symbol(xp,yp,.1,id,0.,68)
    saveid=plotid
    yp=yp-.15
    call symbol(xp,yp,.1,headng,0.,52)
    yp=yp-.15
    dummy=9999.
    write(plbl1,2000)ident,freq,ipwr,zplane,ral,raduis,v,psi,iclock
2000  format(a1,1x,f6.2,1x,i4,3(1x,f5.2),1x,f5.1,1x,f5.1,1x,i4)
        call symbol(xp,yp,.1,iplbl1,0.,52)
        xp=0.
        yp0=yp
    else
        call plton
        yp=yp0-.15
        write(plbl2,2000)ident,freq,ipwr,zplane,ral,raduis,v,psi,iclock
c
c      check for common data in plot label
        if(plbl2( 1:1 ) .eq. plbl1( 1:1 ))
$          plbl2( 1:1 )=' '
        if(plbl2( 3:8 ) .eq. plbl1( 3:8 ))
$          plbl2( 3:8 )=' '
        if(plbl2(10:13) .eq. plbl1(10:13))
$          plbl2(10:13)=' '
        if(plbl2(15:19) .eq. plbl1(15:19))
$          plbl2(15:19)=' '
        if(plbl2(21:25) .eq. plbl1(21:25))
$          plbl2(21:25)=' '
        if(plbl2(27:31) .eq. plbl1(27:31))
$          plbl2(27:31)=' '
        if(plbl2(33:37) .eq. plbl1(33:37))
$          plbl2(33:37)=' '
        if(plbl2(39:43) .eq. plbl1(39:43))
$          plbl2(39:43)=' '
        if(plbl2(45:48) .eq. plbl1(45:48))
$          plbl2(45:48)=' '
c
        if(plotid .eq. saveid) then
            pflag=.false.
        else
            call symbol(xp,yp,.1,id,0.,68)
            pflag=.true.
        end if
        if(plbl2 .ne. plbl1 .and.
$          plbl2 .ne. blank) then
            if(pflag) then
                yp=yp-.15
                call symbol(xp,yp,.1,headng,0.,52)
                yp=yp-.15
            end if
            call symbol(xp,yp,.1,iplbl2,0.,52)
        end if

```

```

    end if
c
    yl(1)=yp+.05
    yl(2)=yp+.05
    call curve(xl,yl,ul,2,0.,0.,1.,1.,line)
c
c    draw curves
    nrcrvs=nrcrvs+1
    if(iopt .eq. 1) then
        call curve(xy,outl,up,nrpts,xmin,ymin,(xmax-xmin)/sizex,
$              (ymax-ymin)/sizey,line)
    else
        call curve(outl,xy,up,nrpts,xmin,ymin,(xmax-xmin)/sizex,
$              (ymax-ymin)/sizey,line)
    end if
c
    if(nplot .ge. 2) 30,40,50
c
1001  format(' ',al,' COMP    RALT = ',f7.3/
$           4(' DIST    AMPLITUDE  PHASE',7x))
1003  format(' ',al,' COMP    DIST = ',f6.3/
$           4(' RALT    AMPLITUDE  PHASE',7x))
1011  format(4(f7.3,2f10.4,5x))
    end

```

```

subroutine mcstep
c
c calculate mode conversion coefficients
c
parameter (maxmds=30)
c
implicit real*8 (a-h,o-z)
common/mc inpt/xtra(3,maxmds),temp(maxmds),freq,omega,waveno,mik,
$      alpha,ak,ak13,ka13,ka23,ngsq,nthsq,skip1(3)
common/mc stor/a(maxmds,maxmds),fofr(maxmds),s(maxmds),tp(maxmds),
$      skip2(3),nremode,nrslab
common/mc plot/iskipl(78),nprint
common norm(maxmds,maxmds),capi(maxmds),ans(maxmds),ps(maxmds),
$      ex0(maxmds), ey0(maxmds), hx0(maxmds), tau(maxmds),
$      pex0(maxmds),pey0(maxmds),phx0(maxmds),ptau(maxmds),
$      ext(maxmds), eyt(maxmds), hxt(maxmds), hyt(maxmds),
$      pext(maxmds),peyt(maxmds),phxt(maxmds),phyt(maxmds)
complex*16 thetap,fofr,xtra,temp,ans,tp,a,s,ssq,sj,sm,tj,tm,ps,
$      q0,h10,h20,h1prm0,h2prm0,qt,hlt,h2t,hlprmt,h2prmt,
$      a1,a2,a3,a4,mik,ey0j,ey0m,
$      fprp,dfprp,fprl,dfprl,mult,arbt,argt,arg0,argg,norm,capi,
$      ex0, ext, ey0, eyt, hx0, hxt, hyt, ngsq, tau,
$      pex0,pext,pey0,peyt,phx0,phxt,phyt,pngsq,ptau,
$      one,zero,w
real*8 ka13,ka23,nthsq
integer pnmode
data      one/(1.d0,0.d0)/,zero/(0.d0,0.d0)/
data      w/(0.d0,-1.45749544d0)/
c
do 90 m=1,nremode
thetap=m
ssq=s(m)**2
tm=zsqr(ngsq-ssq)
tau(m)=tm
a2=dcmplx(0.d0,ka13)*tm
a1=a2/ngsq
q0=ka23*(one-ssq)
call mdhnkl(q0,h10,h20,h1prm0,h2prm0,thetap,'MC0 ')
ex0(m)=-tm/ngsq
ey0(m)=fofr(m)
hx0(m)=tm*fofr(m)
c
hy0 =one
qt=ka23*(nthsq-ssq)
call mdhnkl(qt,hlt,h2t,hlprmt,h2prmt,thetap,'MCT ')
a3=hlt *h20 -h10 *h2t
a4=hlt *h2prm0-h1prm0*h2prmt
fprl=a4-a1*a3
fprp=a4-a2*a3
a3=h1prm0*h20 -h10 *h2prmt
a4=h1prm0*h2prm0-h1prm0*h2prmt
dfprl=a4-a1*a3
dfprp=a4-a2*a3
ext(m)=dcmplx(0.d0,ak13)*dfprl/w
eyt(m)=ey0(m)*fprp/w
hxt(m)=dcmplx(0.d0,-ak13)*ey0(m)*dfprp/w

```

```

90      hyt(m)=fpr1/w
      continue
c
      if(nrslab .eq. 1) then
c
c      first slab
      do 32 m=1,nrmode
      do 32 j=1,nrmode
      if(j .eq. m) then
          a(j,m)=one
      else
          a(j,m)=zero
      end if
32      continue
c
      else
c
c      integrals in current slab
      if(nprint .gt. 3) print 906,nrslab
      do 140 m=1,nrmode
      sm=s(m)
      tm=tau(m)
      ey0m=ey0(m)
      if(nprint .gt. 3) print 902
      do 140 j=1,nrmode
      if(j .eq. m) then
          modes are equal
          mult=sm*(2.d0/alpha)
          ssq=sm**2
          q0=one-ssq
          qt=nthsq-ssq
          argt=temp(m)*(qt*eyt(m)**2-hxt(m)**2)+(qt*hyt(m)**2-ext(m)**2)
          arg0=temp(m)*(q0*ey0(m)**2-hx0(m)**2)+(q0          -ex0(m)**2)
          argg=(one+ey0m**2)*sm/(mik*tm)
      else
          sj=s(j)
          tj=tau(j)
          ey0j=ey0(j)
          mult=one/(mik*(sj-sm))
          argt=temp(m)*(eyt(m)*hxt(j)-eyt(j)*hxt(m))
          -          (hyt(m)*ext(j)-hyt(j)*ext(m))
          arg0=temp(m)*(ey0(m)*hx0(j)-ey0(j)*hx0(m))
          -          (ex0(j)-          ex0(m))
          argg=(one+ey0j*ey0m)*(sj+sm)/(mik*(tj+tm))
      end if
      norm(j,m)=mult*(argt-arg0)-argg
      if(nprint .gt. 3) print 908,m,j,norm(j,m)
140      continue
c
      if(nthsq .ne. pnthsq) then
c      previous slab had different topht, must recompute fields
      do 200 j=1,pnmode
      thetap=j
      ssq=ps(j)**2
      a2=dcmplx(0.d0,ka13)*ptau(j)

```

```

al=a2/pngsq
q0=ka23*(one-ssq)
call mdhnkl(q0,h10,h20,h1prm0,h2prm0,thetap,'MCPO')
qt=ka23*(nthsq-ssq)
call mdhnkl(qt,hlt,h2t,hlprmt,h2prmt,thetap,'MCPT')
a3=hlt *h20 -h10 *h2t
a4=hlt *h2prm0-hlprm0*h2t
fprl=a4-al*a3
fprp=a4-a2*a3
a3=hlprmt*h20 -h10 *h2prmt
a4=hlprmt*h2prm0-hlprm0*h2prmt
dfprl=a4-al*a3
dfprp=a4-a2*a3
pext(j)=dcmplx(0.d0,ak13)*dfprl/w
peyt(j)=pey0(j)*fprp/w
phxt(j)=dcmplx(0.d0,-ak13)*pey0(j)*dfprp/w
phyt(j)=fprl/w
200  continue
end if
c
c      integrals across slab boundary
init=0
if(nprint .gt. 2) print 900,nrslab
c
do 500 j=1,pnmode
sj=ps(j)
sjr=sj
sji=sj*(0.d0,-1.d0)
tj=ptau(j)
ey0j=pey0(j)
if(nprint .gt. 2) print 902
c
do 400 m=1,nrmode
sm=s(m)
smr=sm
smi=sm*(0.d0,-1.d0)
tm=tau(m)
ey0m=ey0(m)
if(smr .eq. sjr .and. smi .eq. sji) then
c      modes are equal
mult=sm*(2.d0/alpha)
ssq=sm**2
q0=one-ssq
qt=nthsq-ssq
argt=temp(m)*(qt*eyt(m)**2-hxt(m)**2)+(qt*hxt(m)**2-ext(m)**2)
arg0=temp(m)*(q0*ey0(m)**2-hx0(m)**2)+(q0          -ex0(m)**2)
argg=(one+ey0m**2)*sm/(mik*tm)
else
mult=one/(mik*(sj-sm))
argt=temp(m)*(eyt(m)*phxt(j)-peyt(j)*hxt(m))
$      - (hxt(m)*pext(j)-phyt(j)*ext(m))
arg0=temp(m)*(ey0(m)*phx0(j)-pey0(j)*hx0(m))
$      - (pex0(j)-ex0(m))
argg=(one+ey0j*ey0m)*(sj+sm)/(mik*(tj+tm))
end if

```

```

capi(m)=mult*(argt-arg0)-argg
if(nprint .gt. 3) print 910,m,j,capi(m)
400 continue
c
c calculate conversion coefficients for hy
call clineq(norm,capi,ans,nrmode,maxmds,init,err)
init=1
if(nprint .gt. 3) print 902
do 430 m=1,nrmode
a(j,m)=ans(m)
if(nprint .gt. 2) then
  ar=ans(m)
  ai=ans(m)*(0.d0,-1.d0)
  db=10.*dlog10(ar*ar+ai*ai)
  ang=datan2(ai,ar)*57.2957795d0
  print 903,m,j,ar,ai,db,ang
end if
430 continue
c
500 continue
end if
c
c save data for next slab
pngsq=ngsq
pnthsq=nthsq
pnmode=nrmode
do 60 j=1,pnmode
ps(j)=s(j)
ptau(j)=tau(j)
pex0(j)=ex0(j)
pey0(j)=ey0(j)
phx0(j)=hx0(j)
pext(j)=ext(j)
peyt(j)=eyt(j)
phxt(j)=hxt(j)
60 phyt(j)=hyt(j)
return
c
900 format('0conversion coefficients for slab ',i2)
901 format(' A(',i2,',',i2,')-',1p2e15.5,5x,
$      '20*log10(A)-',0p2f10.3)
902 format(' ')
903 format(' T(',i2,',',i2,')-',1p2e15.5,5x,
$      '20*log10(T)-',0p2f10.3)
906 format('0Integrals in slab',i3)
908 format(' Norm(',      i2,',',i2,') -',1p2e15.6)
910 format(' Capi(',      i2,',',i2,') -',1p2e15.6)
end

```

```

c subroutine rpower
c subroutine to calculate the radiated power - pw
c
c parameter (maxsgs=50)
c implicit real*8 (a-h,o-z)
c
c real*8 j12,j32,j52
c real*4 pin
c real*4 gamma,phi
c real*8 i0,idl,idlsav,moment,ms
c dimension moment(maxsgs),ms(maxsgs),sbar(maxsgs),r(maxsgs,maxsgs)
c
c common/com01/antlen(maxsgs),antrad(maxsgs),antalt(maxsgs),
c $ antang(maxsgs),npts
c common/com02/cpl,psi,iclock,chicp
c common/com03/x(maxsgs),y(maxsgs),z(maxsgs)
c common/com04/xmid(maxsgs),ymid(maxsgs),zmid(maxsgs)
c common/com05/gamma(maxsgs),phi(maxsgs)
c common/com06/idl(maxsgs)
c common/mc inpt/skip1(242),waveno,skip2(13)
c common/mc plot/skip3(27),pin,skip4(24)
c
c pi=3.1415926536
c nsegs=npts-1
c
c antlen(npts+1)=antlen(npts)+cpl
c antalt(npts+1)=antalt(npts)
c
c convert lengths to kilometers
c do i=1,npts+1
c     antlen(i)=antlen(i)*0.3048d-3
c     antalt(i)=antalt(i)*0.3048d-3
c enddo
c do i=1,nsegs+1
c     xmid(i)=xmid(i)*0.3048d-3
c     ymid(i)=ymid(i)*0.3048d-3
c     zmid(i)=zmid(i)*0.3048d-3
c enddo
c
c do i=1,nsegs+1
c     sbar(i)=antlen(i+1)-antlen(i)
c     moment(i)=sin(waveno*((antlen(i)+antlen(i+1))/2.0))
c     ms(i)=moment(i)*sbar(i)
c enddo
c
c sumeq=0.0
c sum=0.0
c do n=1,nsegs+1
c     do m=1,n
c         zp=waveno*(zmid(n)+zmid(m))
c         zpsq=zp*zp
c         cosgnm=cos(gamma(n))*cos(gamma(m))
c         ssqgnm=sin(gamma(n))*sin(gamma(m))
c         cospnm=cos(phi(n)-phi(m))
c         singnm=0.5*sin(gamma(n))*sin(gamma(m))*cospnm

```

```

if(n .eq. m) then
  czp=cos(zp)
  szp=sin(zp)
  zpcu=zpsq*zp
  term=(1.0+3.0/zpcu*(szp-zp*czp))*cosgnm
$    +(1.0+1.5/zpcu*((1.0-zpsq)*szp-zp*czp))*ssqgnm
  sumeq=sumeq+ms(n)*ms(m)*term
else
  zm=waveno*(zmid(n)-zmid(m))
  zmsq=zm*zm
  r(n,m)=waveno*sqrt((xmid(n)-xmid(m))**2+(ymid(n)-ymid(m))**2)
  rsq=r(n,m)*r(n,m)
  wm=sqrt(zmsq+rsq)
  wmm1=1.0/wm
  wmm12=sqrt(wmm1)
  wmm32=wmm1*wmm12
  wmm52=wmm1*wmm32
  wp=sqrt(zpsq+rsq)
  call jfunct(wm,j12,j32,j52)
  term1=( cosgnm+singnm)*wmm12*j12
  term3=(-cosgnm+singnm)*wmm32*(j32-zmsq*wmm1*j52)
  if(xmid(n) .eq. xmid(m)) then
    if(ymid(n) .eq. ymid(m)) then
      phinm=0.0
    else
      if(ymid(n) .gt. ymid(m)) then
        phinm=pi/2.0
      else
        phinm=-pi/2.0
      endif
    endif
  else
    phinm=atan2(ymid(n)-ymid(m),xmid(n)-xmid(m))
  endif
  cospm=cos(phinm-phi(m))
  cospn=cos(phinm-phi(n))
  cos2p=cos(2.0*phinm-phi(n)-phi(m))
  cscnm=cos(gamma(n))*sin(gamma(m))*cospm
  cscmn=cos(gamma(m))*sin(gamma(n))*cospn
  ssc=0.5*sin(gamma(n))*sin(gamma(m))*cos2p
  term5=(cscnm*zm+cscmn*zm+ssc*r(n,m))*r(n,m)*wmm52*j52
  call jfunct(wp,j12,j32,j52)
  wpml=1.0/wp
  wpml2=sqrt(wpml)
  wpm32=wpml*wpml2
  wpm52=wpml*wpm32
  term2=( cosgnm-singnm)*wpml2*j12
  term4=( cosgnm+singnm)*wpm32*(j32-zpsq*wpml*j52)
  term6=(-cscnm*zp+cscmn*zp-ssc*r(n,m))*r(n,m)*wpm52*j52
  sum=sum+ms(n)*ms(m)*(term1+term2+term3-term4+term5+term6)
endif
enddo
enddo
pw=20.0*waveno*waveno*sumeq
$  +60.0*waveno*waveno*sum

```

```
i0=sqrt(pin*1.0e3/pw)
do i=1,nsegs+1
  idl(i)=i0*ms(i)*1.0e3
enddo
return
end
```

```
SUBROUTINE JFUNCT(Q,J12,J32,J52)
c
implicit real*8 (a-h,o-z)
REAL*8 J12,J32,J52

SINQ=SIN(Q)
COSQ=COS(Q)
RTQ=SQRT(Q)
J12=SINQ/RTQ
J32=(-COSQ+J12/RTQ)/RTQ
J52=3.*J32/Q-J12
RETURN
END
```

```

        subroutine tacamo
c
        implicit real*8 (a-h,o-z)
        parameter (maxsgs=50,maxmds=30)
        TOWPLANE STEADY STATE CONFIGURATION...towplane in circular orbit
c
c      v      towplane true airspeed,knots
c      rpl    towplane turn radius(feet) for straight and level flight
c      zpl    towplane density altitude ft.
c      amg    drogue weight,lbs.
c      abase  drogue base area,sq. ft.
c      cddrog drogue drag coefficient
c      amug   towline weight,lb/ft
c      d      towline diameter,ft.
c      al     towline length,ft.
c      picf   towline skin friction coefficient
c      cd     towline drag coefficient
c      x      distance from towpoint to drogue center of gravity,ft.
c      xcp   distance from towpoint to drogue center of pressure,ft.
c      alpha  pitch angle of drogue centerline(radians),positive is nose up
c      cappal side slip angle in radians,towpoint left positive
c
c
c
        dimension dsstor(17)
        common/com01/antlen(maxsgs),antrad(maxsgs),antalt(maxsgs),
$              antang(maxsgs),npts
        common/com02/cpl,psi,iclock,chicp
        common/com09/v,rpl,zpl
        common/mc inpt/skip1(8,maxmds),freq,skip2(15)
c
        namelist/tacin/v,rpl,zpl,rzd,zzd,amg,psi,iclock,itrset,cpl,chicp
        data g/32.17/,pi/3.1416/,acl/.53/,acm/- .68/,x/1.34/,xcp/2.31/,
$      abase/5.6/,cddrog/.6/,amug/1.095e-1/,d/1.75e-2/,dds/1.e3/,
$      picf/2.2e-2/,cd/1.03/,delr/5.0/,delz/50.0/
        data dsstor/50.,130.,4*200.,4*300.,4*400.,2*600.,1000./
c
c
        read tacin
        print tacin
        al=4.9179d+5/freq-cpl
        iter=1
        print 1101,v,rpl,zpl,rzd,zzd
        print 1102,amg,abase,cddrog
        print 1103,amug,d,al,dds,picf,cd
        ddrog=sqrt(4.*abase/pi)
        if(cd .le. .1) stop
        k=1
        istop=0
        index=0
5      iter=iter+1
        if(iter .gt. 30) then
          print 1000
          stop
        endif

```

```

16    continue
zz=zzd
rz=rzd
i=1
ds=20.
omega=v*1.69/rpl
m=1
arg=1.-.006875*zz/1000.
if(arg .gt. 0.)then
  rhoz=0.002378*arg**4.256
else
  print *, 'does not converge'
  stop
end if
omegsq=omega*omega
s=0.
thz=0.
qs=.5*rhoz*rz*rz*omegsq*abase
a=0.5*amg*x/qs+acl*x*.04
b=(acl+cddrog)*x-ddrog*acm
c=-0.04*acl*x-amg*x/qs
alpha=(-b+sqrt(b*b-4.*a*c)).5/a
if(alpha .ge. .8) then
  a2=.85*qs*xcp
  b2=-amg*x-.85*pi*qs*xcp
  c2=amg*x*pi*.5-.85*qs*xcp
  alpha=(-b2-b2-4.*a2*c2)).5/a2
  m=2
  am=amg/g
endif
al=-amg/g*rz*omegsq-qs*acl*.04
b1=qs*(ddrog*acm/(x*cos(alpha))-acl-cddrog)
cappal=al/b1
if(cappal .le. .04) then
  trpz=-amg/g*rz*omegsq
else
  trpz=-amg/g*rz*omegsq+acl*(cappal-.04)*qs
endif
if(alpha .le. .04) then
  tzpz=amg
  trthpz=0.5*rhoz*abase*cddrog*rz*rz*omegsq
else
  if(m .eq. 1) then
    tzpz=amg-acl*(alpha-.04)*qs
    trthpz=0.5*rhoz*abase*cddrog*rz*rz*omegsq
  else
    if(m .ne. 2) stop
    tzpz=amg-.85*qs*sin(alpha)**2.*cos(alpha)
    trthpz=.85*qs*sin(alpha)**3.
  endif
endif
tz=sqrt(trpz*trpz+trthpz*trthpz+tzpz*tzpz)
rpz=trpz/tz
thpz=trthpz/(tz*rz)
zpz=tzpz/tz

```

```

rthpz=thpz*rz
npts=1
if(mod(index,3) .eq. 0 .or. k .eq. 4) then
  print 1
  print 21,s,rz,zz,thz,tz,rpz,zpz,rthpz
endif
if(k .eq. 4) then
  antlen(npts)=s
  antrad(npts)=rz
  antalt(npts)=zz
  antang(npts)=thz
endif
8 s=s+ds
npts=npts+1
if(npts .gt. maxsgs-2) then
  print *, 'number of segments too big'
  stop
endif
z=zz
t=tz
r=rz
rp=rpz
thp=thpz
zp=zpz
kk=1
10 za=.5*(z+zz)
ta=.5*(t+tz)
ra=.5*(r+rz)
thpa=.5*(thp+thpz)
zpa=.5*(zp+zpz)
rpa=.5*(rp+rpz)
arg=1..006875*za/1000.
if(arg .gt. 0.)then
  rho=.002378*arg**4.256
else
  print *, 'does not converge'
  stop
end if
thpasq=thpa*thpa
rasq=ra*ra
qd=.5*rho*d*rasq*omegsq*cd
strth=sqrt(1.-rasq*thpasq)
trp=(ta*ra*thpasq-amug/g*ra*omegsq-qd*ra*rpa*thpa*strth)*ds+trpz
trthp=(-ta*rpa*thpa+qd*strth**3.+.5*rho*d*picf*rasq*omegsq)*ds+
$      trthpz
tzp=(amug-qd*ra*thpa*zpa*strth)*ds+tzpz
t1=sqrt(trp*trp+trthp*trthp+tzp*tzp)
rpl=trp/t1
r1=rz+(rpl+rpz)*.5*ds
thpl=trthp/(t1*r1)
zpl=tzp/t1
z1=zz+.5*(zpl+zpz)*ds
rthpl=thpl*r1
th1=thz+(thpz+thpl)*.5*ds
if(abs((z1-z)/z) .gt. .001) go to 100

```

```

if(abs((r1-r)/r) .gt. .001) go to 100
if(abs((t1-t)/t) .gt. .001) go to 100
32 if(l .le. i .and. i .le. 17) then
    ds=dsstor(i)
else
    if(i .eq. 18) then
        if(s-al+1.0e-4 .eq. 0.0) then
            ds=dds
        else
            if(s-al+1.0e-4 .lt. 0.0) then
                go to 50
            else
                go to 190
            endif
        endif
    else
        print *, ' i is not between 1 and 18'
        stop
    endif
endif
i=i+1
50 zz=z1
rz=r1
tz=t1
rpz=rpl
thpz=thpl
zpz=zpl
thz=thl
trpz=trp
trthpz=trthp
tzpz=tzp
if(al-s .lt. 1000.)ds=al-s
if(k .eq. 4) then
    print 21,s,r1,z1,th1,t1,rpl,zpl,rthpl
    antlen(npts)=s
    antrad(npts)=r1
    antalt(npts)=z1
    antang(npts)=th1
endif
go to 8
100 if(kk .gt. 20) then
    print 3
    go to 32
endif
z=z1
r=r1
t=t1
rp=rpl
thp=thpl
zp=zpl
rthp=rthpl
kk=kk+1
go to 10
190 continue
if(mod(index,3) .eq. 0 .or. k .eq. 4)

```

```

$  print 21,s,r1,z1,th1,t1,rpl,zpl,rthpl
  if(k .eq. 4) then
    antlen(npts)=s
    antrad(npts)=r1
    antalt(npts)=z1
    antang(npts)=th1
  endif
  if( iter .gt. itrset) go to 18
  go to(200,203,18,999),k
200 if(abs((z1-zpl)/zpl)-.010)202,210,210
202 go to(204,240),k
203 if(abs(z1-zpl)-2000.)204,204,210
204 if(abs((r1-rpl)/rpl)-.003)206,220,220
206 go to(240,200),k
210 k=1
  zzd=zzd+.6*(zpl-z1)
  go to 5
220 if(k .eq. 1) then
  drzd=.16*(rpl-r1)
  else
    if(k .eq. 2) then
      if(abs((r1-rstore)/rpl) .le. .002) drzd=.2*(rpl-r1)
      drzd=(rpl-r1)*drzd*.6/(r1-rstore)
      if(abs(drzd) .gt. 150.) then
        drzd=150.*drzd/abs(drzd)
      else
        if(abs(drzd) .le. 5.) drzd=5.*drzd/abs(drzd)
      endif
    else
      print *, ' k is not 1 or 2'
      stop
    endif
  endif
  rzd=rzd+drzd
  k=2
  rstore=r1
  go to 5
240 k=3
18  continue
  if(index .gt. 30)go to 1199
  if(istop .eq. 500)go to 999
  if(mod(index,3) .eq. 0)then
    if(abs((z1-zpl)/zpl) .lt. .001 .and. abs((r1-rpl)/rpl) .lt.
$      .001)go to 17
    f1=z1-zpl
    f2=r1-rpl
    zlsav=z1
    rlsav=r1
    zzdsav=zzd
    rzdsav=rzd
    zzd=zzd+delz
    index=index+1
    go to 16
  else
    if(mod(index,3) .eq. 1)then

```

```

dzldzd=(z1-z1sav)/delz
drldzd=(r1-rlsav)/delz
zzd=zzdsav
rzd=rzdsav+delr
index=index+1
go to 16
else
dzldrd=(z1-z1sav)/delr
drldrd=(r1-rlsav)/delr
den=dzldzd*drldrd-drldzd*dzldrd
delzd=(f2*dzldrd-f1*drldrd)/den
delrd=(f1*drldzd-f2*dzldzd)/den
zzd=zzdsav+delzd
rzd=rzdsav+delrd
index=index+1
go to 16
end if
end if
17 k=4
istop=500
go to 16
999 return
1199 print *, 'does not converge'
stop
c
1 format(lh ,5x,1hs,11x,1hr,11x,1hz,11x,2hth,10x,1ht,10x,2hrp,10x,
$      2hzp,9x,4hrthp)
2 format(8e12.4)
21 format(8e12.4)
3 format(13h not converge)
1000 format(1h1,14hrlnot converge)
1101 format(lh ,8hv(knot)=,e12.4,2x,4hrpl=,e12.4,2x,4hzpl=,e12.4,2x,
$      4hrzd=,e12.4,2x,4hzzd=,e12.4)
1102 format(lh ,4hamg=,e12.4,2x,6habase=,e12.4,2x,7hcddrog=,e12.4)
1103 format(lh ,5hamug=,e12.4,2x,2hd=,e12.4,2x,3hal=,e12.4,2x,4hdds=,
$      e12.4,2x,5hpicf=,e12.4,2x,3hcd=,e12.4)
1203 format(lh ,3x,6halpha=,e12.4,5x,7hcappal=,e12.4)
c
end

```

```

SUBROUTINE HTGAIN(IOPT,FREQ,SIGMA,EPSR,ALPHA,NRMODE,TP,Z,HG)
IMPLICIT REAL*8 (A-H,O-Z)
COMPLEX*16 TP(1),HG(3,1),HGO,
$           C,SSQ,NGSQ,SQROOT,RATIO,A1,A2,A3,A4,MI,ONE
$           P0,H10,H20,H1PRM0,H2PRM0,H1Z,H2Z,H1PRMZ,H2PRMZ,EXPZ
REAL*8 K,KA13,KA23
DATA MI/(0.D0,-1.D0)/,ONE/(1.D0,0.D0)/,HGO/(0.D0,1.45749544D0)/
DATA DTR/1.745329252D-02/
C
      NGSQ=DCMPLX(EPSR,-SIGMA/(5.5633459D-8*FREQ))
      K=2.0958426D-02*FREQ
      IF(ALPHA .EQ. 0.D0) GO TO 5
      AK=ALPHA/K
      AK13=DEXP(DLOG(AK)/3.D0)
      AK23=AK13**2
      KA13=1.D0/AK13
      KA23=KA13**2
      P1=KA23*ALPHA*Z
      EXPZ=DEXP(.5D0*ALPHA*Z)
      DO 20 M=1,NRMODE
      SSQ=ZSIN(TP(M)*DTR)**2
      CSQ=ONE-SSQ
      SQROOT=ZSQRT(NGSQ-SSQ)
      IF(DIMAG(TP(M)) .LE. -10.D0 .OR. ALPHA .EQ. 0.D0) GO TO 10
      P0=KA23*(ONE-SSQ)
      CALL MDHNKL(P0 ,H10,H20,H1PRM0,H2PRM0,TP(M),'HG 1')
      CALL MDHNKL(P0+P1,H1Z,H2Z,H1PRMZ,H2PRMZ,TP(M),'HG 2')
      A1=H10 *H2Z -H1Z *H20
      A2=H1PRM0*H2Z -H1Z *H2PRM0
      A3=H10 *H2PRMZ-H1PRMZ*H20
      A4=H1PRM0*H2PRMZ-H1PRMZ*H2PRM0
      RATIO=SQROOT/NGSQ
      C=.5D0*AK23+KA13*MI*RATIO
      HG(1,M)=EXPZ*(C*A1+A2)
      HG(2,M)=KA13*MI*SQROOT*A1+A2
      HG(3,M)=.5D0*AK*MI*HG(1,M)+AK13*MI*EXPZ*(C*A3+A4)
      IF(IOPT .EQ. 1) GO TO 20
      HG(1,M)=HG(1,M)/HGO
      HG(2,M)=HG(2,M)/HGO
      HG(3,M)=HG(3,M)/(RATIO*HGO)
      GO TO 20
10     C=ZSQRT(ONE-SSQ)
      EXPZ=ZEXP(DCMPLX(0.D0,K*Z)*C)
      A1=(NGSQ*C-SQROOT)/(NGSQ*C+SQROOT)
      A2=(C-SQROOT)/(C+SQROOT)
      HG(1,M)=EXPZ+A1/EXPZ
      HG(2,M)=EXPZ+A2/EXPZ
      HG(3,M)=(EXPZ-A1/EXPZ)*C
      IF(IOPT .EQ. 1) GO TO 20
      HG(1,M)=HG(1,M)/(ONE+A1)
      HG(2,M)=HG(2,M)/(ONE+A2)
      HG(3,M)=HG(3,M)/((ONE-A1)*C)
20     CONTINUE
      RETURN
      END

```

```

SUBROUTINE MDHNKL (Z,H1,H2,H1PRME,H2PRME,THETA,>IDBG)
IMPLICIT COMPLEX*16 (A-H,O-Z)
COMPLEX*16 I,MPOWER,MTERM
REAL*8 A,B,C,D,CAP,PART1,PART2,ZMAG
CHARACTER*4 IDBG
DIMENSION A(30), B(30), C(30), D(30), CAP(30), PART1(2), PART2(2)
EQUIVALENCE (PART1,TERM4), (PART2,SUM4)
DATA A    / 9.3043671692922944819D-01, 3.1014557230974314911D+01,
$           2.0676371487316209897D+02, 5.7434365242545027449D+02,
$           8.7021765519007617234D+02, 8.2877871922864397320D+02,
$           5.4168543740434246542D+02, 2.5794544638302022111D+02,
$           9.3458495066311674231D+01, 2.6626351870744066662D+01,
$           6.1210004300561072794D+00, 1.1592803844803233472D+00,
$           1.8401275944132116616D-01, 2.4833030963741048003D-02,
$           2.8842080097260218300D-03, 2.9133414239656786138D-04,
$           2.5827494893312753646D-05, 2.0256858739853140063D-06,
$           1.4155736366074870734D-07, 8.8695090013000443124D-09,
$           5.0110220346327933889D-10, 2.5658074934115685526D-11,
$           1.1961806496091228666D-12, 5.0988092481207283185D-14,
$           1.9948392989517716388D-15, 7.1886100863126905797D-17,
$           2.3938095525516785112D-18, 7.3883010881224645255D-20,
$           2.1194208514407528762D-21, 5.6653858632471341093D-23/
DATA B    / 6.7829872514427588456D-01, 1.1304978752404598033D+01,
$           5.3833232154307609704D+01, 1.1962940478735024376D+02,
$           1.5337103177865415841D+02, 1.2780919314887846509D+02,
$           7.4742218215718400631D+01, 3.2355938621523117060D+01,
$           1.0785312873841039006D+01, 2.8532573740320209005D+00,
$           6.1360373635097223595D-01, 1.0937678009821251966D-01,
$           1.642293995468656465D-02, 2.1055051223957133911D-03,
$           2.3316778764072130571D-04, 2.2528288660939256561D-05,
$           1.9156708045016374595D-06, 1.4446989475879618839D-07,
$           9.7286124416697769730D-09, 5.8854279743918795891D-10,
$           3.2160808603234314644D-11, 1.5952782045255116351D-12,
$           7.2151886229105003778D-14, 2.9876557444763976717D-15,
$           1.1368553061173507104D-16, 3.9889659863766691603D-18,
$           1.2946984700995355913D-19, 3.8985199340546088228D-21,
$           1.0920223904914870636D-22, 2.8527230681595795812D-24/
DATA C    / 4.6521835846461472410D-01, 6.2029114461948629822D+00,
$           2.5845464359145262382D+01, 5.2213059311404570392D+01,
$           6.2158403942148298012D+01, 4.8751689366390821897D+01,
$           2.7084271870217123228D+01, 1.1215019407957400909D+01,
$           3.5945575025504490022D+00, 9.1815006450841609147D-01,
$           1.9128126343925335199D-01, 3.3122296699437809740D-02,
$           4.8424410379295043444D-03, 6.0568368204246458321D-04,
$           6.5550182039227768583D-05, 6.1985987743950608612D-06,
$           5.1654989786625507119D-07, 3.8220488188402150986D-08,
$           2.5278100653705126277D-09, 1.5033066103898380141D-10,
$           8.0822936042464409157D-12, 3.9473961437101054471D-13,
$           1.7590891906016512675D-14, 7.1814214762263778920D-16,
$           2.6957287823672589641D-17, 9.3358572549515461865D-19,
$           2.9922619406895981315D-20, 8.9015675760511620701D-22,
$           2.4644428505125033375D-23, 6.3656020935361057409D-25/
DATA D    / 6.7829872514427588456D-01, 4.5219915009618392131D+01,
$           3.7683262508015326776D+02, 1.1962940478735024344D+03,
$           1.9938234131225040548D+03, 2.0449470903820554375D+03,

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$ 1.4201021460986496090D+03, 7.1183064967350857463D+02,
$ 2.6963282184602597492D+02, 7.9891206472896585111D+01,
$ 1.9021715826880139294D+01, 3.7188105233392256682D+00,
$ 6.0764877832340288572D-01, 8.4220204895828535644D-02,
$ 1.0026214868551016149D-02, 1.0363012784032058021D-03,
$ 9.3867869420580235442D-05, 7.5124345274574017960D-06,
$ 5.3507368429183773360D-07, 3.4135482251472901638D-08,
$ 1.9618093247972931935D-09, 1.0209780508963274472D-10,
$ 4.8341763773500352579D-12, 2.0913590211334783723D-13,
$ 8.2990437346566602039D-15, 3.0316141496462685641D-16,
$ 1.0228117913786331176D-17, 3.1967863459247792364D-19,
$ 9.2821903191776400453D-21, 2.5103962999804300309D-22/
DATA CAP / 1.0416666666666666663D-01, 8.355034722222222116D-02,
$ 1.2822657455632716019D-01, 2.9184902646414046315D-01,
$ 8.8162726744375764874D-01, 3.3214082818627675264D+00,
$ 1.4995762986862554546D+01, 7.8923013011586517530D+01,
$ 4.7445153886826431887D+02, 3.2074900908906619004D+03,
$ 2.4086549640874004605D+04, 1.9892311916950979121D+05,
$ 1.7919020077753438063D+06, 1.7484377180034121023D+07,
$ 1.8370737967633072978D+08, 2.0679040329451551508D+09,
$ 2.4827519375935888472D+10, 3.1669454981734887315D+11,
$ 4.2771126865134715582D+12, 6.0971132411392560749D+13,
$ 9.1486942234356396792D+14, 1.4413525170009350101D+16,
$ 2.3788844395175757942D+17, 4.1046081600946921885D+18,
$ 7.3900049415704853993D+19, 1.3859220004603943141D+21,
$ 2.7030825930275761623D+22, 5.4747478619645573335D+23,
$ 1.1498937014386333524D+25, 2.5014180692753603969D+26/
DATA I/(0.D0,1.D0)/
DATA ONE/(1.D0,0.D0)/, TWO/(2.D0,0.D0)/, ZERO/(0.D0,0.D0)/
DATA ROOT3/(1.73205080756888D0,0.D0)/
DATA ALPHA/(8.53667218838951D-1,0.D0)/
DATA CONST1/(-2.58819045102522D-01,-9.65925826289067D-01)/
DATA CONST2/(-2.58819045102522D-01, 9.65925826289067D-01)/
DATA CONST3/(-9.65925826289067D-01, 2.58819045102522D-01)/
DATA CONST4/(-9.65925826289067D-01,-2.58819045102522D-01)/
C
ZPOWER=ONE
SUM3=ZERO
SUM4=ZERO
ZMAG=ZABS(Z)
IF(ZMAG .GT. 6.1D0) GO TO 70
SUM1=ZERO
SUM2=ZERO
ZTERM=-Z**3/(200.D0,0.D0)
DO 50 M=1,30
SUM1=SUM1+DCMPLX(A(M),0.D0)*ZPOWER
SUM2=SUM2+DCMPLX(B(M),0.D0)*ZPOWER
SUM3=SUM3+DCMPLX(C(M),0.D0)*ZPOWER
TERM4=DCMPLX(D(M),0.D0)*ZPOWER
SUM4=SUM4+TERM4
IF(DABS(PART1(1)/PART2(1)) .LE. 1.D-17 .AND.
$ DABS(PART1(2)/PART2(2)) .LE. 1.D-17) GO TO 60
50 ZPOWER=ZPOWER*ZTERM
60 GM2F=I*(Z*SUM2-TWO*SUM1)/ROOT3
GPMFP=I*(SUM4+TWO*Z*Z*SUM3)/ROOT3

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H1=Z*SUM2+GM2F
H2=H1-TWO*GM2F
H1PRME=SUM4+GPMFP
H2PRME=H1PRME-TWO*GPMFP
GO TO 999
70  MPOWER=ONE
    SUM1=ONE
    SUM2=ONE
c   RTZ=CDSQRT(Z)
    RTZ=ZSQRT(Z)
    SQRTZB=RTZ*Z
    ZTERM=I/SQRTZB
    MTERM=-ZTERM
    DM=ZERO
    TERM3=ONE
    DO 80 M=1,30
    ZPOWER=ZPOWER*ZTERM
    MPOWER=MPOWER*MTERM
    DM=DM+ONE
    TERM1=DCMPLX(CAP(M),0.D0)*ZPOWER
    TERM2=DCMPLX(CAP(M),0.D0)*MPOWER
    IF(ZABS(TERM2/TERM3) .GE. 1.D0) GO TO 81
    SUM1=SUM1+TERM1
    SUM2=SUM2+TERM2
    SUM3=SUM3+DM*TERM1
    TERM4=DM*TERM2
    SUM4=SUM4+TERM4
    IF(DABS(PART1(1)/PART2(1)) .LE. 1.D-17 .AND.
$      DABS(PART1(2)/PART2(2)) .LE. 1.D-17) GO TO 81
80  TERM3=TERM2
81  ZTERM=(-1.5D0,0.D0)/Z
    SUM3=SUM3*ZTERM
    SUM4=SUM4*ZTERM
    TERM1=((-0.25D0,0.D0)-I*SQRTZB)/Z
    TERM2=((-0.25D0,0.D0)+I*SQRTZB)/Z
c   EXP1=CDEXP((0.D0,0.6666666666666667D0)*SQRTZB)
    EXP1=ZEXP((0.D0,0.6666666666666667D0)*SQRTZB)
    EXP2=CONST1*EXP1
    EXP3=CONST2/EXP1
    EXP4=CONST3*EXP1
    EXP5=CONST4/EXP1
c   ZTERM=ALPHA/CDSQRT(RTZ)
    ZTERM=ALPHA/ZSQRT(RTZ)
    TERM4=Z
    IF(PART1(1) .GE. 0.D0 .OR. PART1(2) .GE. 0.D0) GO TO 90
    H1=ZTERM*(EXP2*SUM2+EXP5*SUM1)
    H1PRME=ZTERM*(EXP2*(SUM2*TERM2+SUM4)+EXP5*(SUM1*TERM1+SUM3))
    GO TO 110
90  H1=ZTERM*EXP2*SUM2
    H1PRME=ZTERM*EXP2*(SUM2*TERM2+SUM4)
110 IF(PART1(1) .GE. 0.D0 .OR. PART1(2) .LT. 0.D0) GO TO 120
    H2=ZTERM*(EXP3*SUM1+EXP4*SUM2)
    H2PRME=ZTERM*(EXP3*(SUM1*TERM1+SUM3)+EXP4*(SUM2*TERM2+SUM4))
    GO TO 999
120 H2=ZTERM*EXP3*SUM1

```

```
H2PRME=ZTERM*EXP3*(SUM1*TERM1+SUM3)
C CALCULATE WRONSKIAN AS PARTIAL CHECK ON VALIDITY
999  SUM4=H1*H2PRME-H1PRME*H2
      IF(DABS(PART2(1)) .LE. 1.D-8 .AND.
      $  DABS(PART2(2)+1.457495441040461D0) .LE. 1.D-8) GO TO 1000
      PRINT 1001,SUM4,THETA,>IDBG
1000 RETURN
1001 FORMAT(' ***** POSSIBLE ERROR IN MDHNKL:  W = ',1P2E15.6,
      $          ' FOR THETA = ',0P2F10.4,' AT ',A4)
      END
```

```

SUBROUTINE CLIN EQ (A, B, X, N, N DIM, IFLAG, ERR)
C
C CLIN EQ USES L-U DECOMPOSITION TO FIND THE TRIANGULAR MATRICES L
C AND U SUCH THAT L*U=A. THE MATRICES L AND U ARE STORED IN A.
C THIS FORM IS USED WITH BACK SUBSTITUTION TO FIND THE SOLUTION X OF
C A*X=L*U*X=B. N IS THE NUMBER OF EQUATIONS AND NDIM IS
C THE DIMENSION OF ALL ARRAYS. ERR IS THE ESTIMATED RELATIVE ERROR
C OF THE SOLUTION VECTOR.
C
C IF IFLAG=0, THEN L, U AND X ARE COMPUTED. OTHERWISE, IT IS
C ASSUMED THAT L AND U HAVE BEEN COMPUTED IN A PREVIOUS CALL AND ARE
C STILL STORED IN A.
C
C IMPLICIT REAL*8 (A-H,O-Z)
C COMPLEX*16 A, B, X, T
C DIMENSION A(N DIM, N DIM), B(NDIM), X(N DIM)
C DIMENSION IROW(51), Q(51)
C DATA EPS /1.D-15/
C
C IF (N .GT. 51) THEN
C   PRINT 999
C   STOP
C END IF
C IF (N .EQ. 1) THEN
C   X(1)=B(1)/A(1,1)
C   RETURN
C END IF
C IF (IFLAG .EQ. 0) THEN
C   DO 50  I=1,N
C   Q(I)=0.D0
C   DO 40  J=1,N
C   QQ=ZABS(A(I,J))
C   40  IF (Q(I) .LT. QQ)  Q(I)=QQ
C   IF (Q(I) .EQ. 0.D0) THEN
C     LOOP=40
C     GO TO 900
C   END IF
C   50  CONTINUE
C   ERR=EPS
C   PPIV=0.D0
C   DO 100  I=1,N
C   100  IROW(I)=I
C
C   DO 500  L=1,N
C   PIVOT=0.D0
C   K=L-1
C   DO 240  I=L,N
C   IF (K .GE. 1) THEN
C     DO 220  J=1,K
C     220  A(I,L)=A(I,L)-A(J,L)*A(I,J)
C   END IF
C   F=ZABS(A(I,L))/Q(I)
C   IF (PIVOT .LE. F) THEN
C     PIVOT=F
C     NPIVOT=I

```

```

        END IF
240    CONTINUE
        IF (PIVOT .EQ. 0.0D0) THEN
            LOOP=240
            GO TO 900
        END IF
        IF (PPIV .GT. PIVOT) ERR=ERR*PPIV/PIVOT
        PPIV=PIVOT
        IF (NPIVOT .NE. L) THEN
            Q(NPIVOT)=Q(L)
            J=IROW(L)
            IROW(L)=IROW(NPIVOT)
            IROW(NPIVOT)=J
            DO 260 I=1,N
                T=A(L,I)
                A(L,I)=A(NPIVOT,I)
                A(NPIVOT,I)=T
260    CONTINUE
        END IF
        IF (L .NE. N) THEN
            T=(1.0D0,0.0D0)/A(L,L)
            K=L+1
            M=L-1
            DO 450 I=K,N
                IF (M .GE. 1) THEN
                    DO 350 J=1,M
                        A(L,I)=A(L,I)-A(L,J)*A(J,I)
                    END IF
                    A(L,I)=T*A(L,I)
450    CONTINUE
        END IF
500    CONTINUE
        IF (ERR .GT. 1.0D-5) PRINT 998,ERR
    END IF
C
    DO 620 I=2,N
620    X(I)=(0.0D0,0.0D0)
    J=IROW(1)
    X(1)=B(J)/A(1,1)
    DO 700 I=2,N
    J=IROW(I)
    K=I-1
    DO 650 L=1,K
650    X(I)=X(I)+A(I,L)*X(L)
    X(I)=(B(J)-X(I))/A(I,I)
700    CONTINUE
    K=N-1
    DO 800 I=1,K
    J=N-I
    M=J+1
    DO 800 L=M,N
        X(J)=X(J)-X(L)*A(J,L)
800    CONTINUE
    RETURN
900    PRINT 997,LOOP

```

```
STOP
997 FORMAT('0*****ERROR IN CLIN EQ, MATRIX IS SINGULAR, AT LOOP ',I3)
998 FORMAT('0*****CAUTION-',
$      'CLIN EQ HAS DECOMPOSED AN ILL-CONDITIONED MATRIX.'/15X,
$      'RESULTS WILL HAVE RELATIVE ERROR =',1PE12.2)
999 FORMAT('0*****ERROR IN CLIN EQ, MATRIX SIZE GREATER THAN 51')
END
```

```

subroutine pltbgn
character*1 answr
logical first,autopl
dimension ia(8),ibuff(2)
data ia/82,79,57,48,73,87,73,80/
c ASCII      R  O  9  O  I  W  I  P
data first/.true./,autopl/.false./
if(first) then
  open(unit=52,file='/dev/plt7550a')
  print *, 'If this is the hp 7550 plotter and you want auto feed,'
  print *, 'then set up the plotter, load a sheet and answer y:'
  print *, 'Do you want auto feed?'
  read 1, answr
1  format(a1)
  if(answr .eq. 'y' .or. answr .eq. 'Y') then
    autopl=.true.
  else
    autopl=.false.
  end if
end if
if(.not.autopl .or. first) then
  print *, 'Set up plotter, enter rotation (y/n) when ready'
  read 1, answr
  first=.false.
end if
call hpinit(2,0,0,0,52)
if(answr .eq. 'y' .or. answr .eq. 'Y')
$  call buff(1,ia,xbuff,8)
  call newpen(1)
  return
end
subroutine plton
dimension ia(3)
data ia/27,46,89/
c ASCII      esc . Y
  call buff(1,ia,xbuff,-3)
  call newpen(1)
  return
end
subroutine pltend
  call newpen(0)
entry pltöff
  call plot(0.0,0.0,0.0,999)
  return
end

```

```

subroutine bordr2(xlbg,xmin,xmax,xtic1,xtic2,ndx,
$                  ylbg,ymin,ymax,ytic1,ytic2,ndy)
c
  xscale=xlbg/(xmax-xmin)
  yscale=ylbg/(ymax-ymin)
  if(xtic1*xscale .le. 0. .or. xtic2*xscale .le. 0.) go to 999
  if(ytic1*yscale .le. 0. .or. ytic2*yscale .le. 0.) go to 999
c
  if(iabs(ndx) .gt. 9) then
    sx=.15
    nx=ndx-(ndx/10)*10
  else
    sx=.1
    nx=ndx
  end if
  xo=.5*sx
  if(iabs(ndy) .gt. 9) then
    sy=.15
    ny=ndy-(ndy/10)*10
  else
    sy=.1
    ny=ndy
  end if
  yo=.5*sy
c
  xres=abs(xtic1)/10.
  yres=abs(ytic1)/10.
c
  t1=.05
  t2=.10
  yval=ymin
  ytc2=ymin
  xp=0.
  yp=0.
  go to 115
112  yval=yval+ytic1
  if(abs(yval-ymax) .le. yres) then
    call plot(0.,ylbg,2)
    if(abs(yval-ytc2) .le. yres) then
      xln=-sy*(3+ny)
      yln=ylbg-yo
      if(abs(yval) .gt. yres .or. abs(yval) .ge. 10.)
$      xln=xln-sy*aint(alog10(abs(yval)))
      if(abs(yval) .lt. yres) yval=0.
      if(yval .lt. 0.) xln=xln-sy
      call plot(xln,yln,3)
      call number(xln,yln,sy,yval,0.,ny)
    end if
    call plot(0.,ylbg,3)
    go to 120
  end if
  yp=(yval-ymin)*yscale
  call plot(xp,yp,2)
  if(abs(yval-ytc2) .gt. yres) go to 118
    call plot(t2,yp,2)

```

```

115      xln=-sy*(3+ny)
      yln=yp-yo
      if(abs(yval) .gt. yres .or. abs(yval) .ge. 10.)
$      xln=xln-sy*aint(alog10(abs(yval)))
      if(abs(yval) .lt. yres) yval=0.
      if(yval .lt. 0.) xln=xln-sy
      call plot(xln,yln,3)
      call number(xln,yln,sy,yval,0.,ny)
      ytc2=ytic2+ytic2
      go to 119
118      call plot(t1,yp,2)
119      call plot(xp,yp,3)
      if(abs(yval-ymax) .gt. yres) go to 112
c
120      yp=yln
      t1=yln-.05
      t2=yln-.10
      xval=xmin
      xtc2=xmin+xtic2
122      xval=xval+xtic1
      if(abs(xval-xmax) .gt. xres) go to 123
          call plot(xln,yln,2)
          if(abs(xval-xtc2) .le. xres) xtc2=xtc2+xtic2
          go to 130
123      xp=(xval-xmin)*xscale
      call plot(xp,yp,2)
      if(abs(xval-xtc2) .gt. xres) go to 128
          call plot(xp,t2,2)
          xtc2=xtc2+xtic2
          go to 129
128      call plot(xp,t1,2)
129      call plot(xp,yp,2)
      if(abs(xval-xmax) .gt. xres) go to 122
c
130      xp=xln
      t1=xln-.05
      t2=xln-.10
      ytc2=ytic2-ytic2
      if(abs(ytc2-ymax) .le. yres) go to 135
132      yval=yval-ytic1
      if(abs(yval-ymin) .gt. yres) go to 133
          call plot(xln,0.,2)
          go to 140
133      yp=(yval-ymin)*yscale
      call plot(xp,yp,2)
      if(abs(yval-ytc2) .gt. yres) go to 138
          call plot(t2,yp,2)
135      ytc2=ytic2-ytic2
          go to 139
138      call plot(t1,yp,2)
139      call plot(xp,yp,2)
      if(abs(yval-ymin) .gt. yres) go to 132
c
140      yp=0.
      t1=.05

```

```

t2=.10
yln=-2.*sx
xtc2=xtc2-xtic2
if(abs(xtc2-xmax) .le. xres) go to 145
142 xval=xval-xtic1
if(abs(xval-xmin) .le. xres) then
  call plot(0.,0.,2)
  if(abs(xval-xtc2) .le. xres) then
    xln=-xo*(2+nx)
    if(abs(xval) .gt. xres .or. abs(xval) .ge. 10.)
    $  xln=xln-xo*aint(alog10(abs(xval)))
    if(abs(xval) .lt. xres) xval=0.
    if(xval .lt. 0.) xln=xln-xo
    call plot(xln,yln,3)
    call number(xln,yln,sx,xval,0.,nx)
  end if
  call plot(0.,0.,3)
  return
end if
xp=(xval-xmin)*xscale
call plot(xp,yp,2)
if(abs(xval-xtc2) .gt. xres) go to 148
  call plot(xp,t2,2)
145  xln=xp-xo*(2+nx)
  if(abs(xval) .gt. xres .or. abs(xval) .ge. 10.)
  $  xln=xln-xo*aint(alog10(abs(xval)))
  if(abs(xval) .lt. xres) xval=0.
  if(xval .lt. 0.) xln=xln-xo
  call plot(xln,yln,3)
  call number(xln,yln,sx,xval,0.,nx)
  xtc2=xtc2-xtic2
  go to 149
148  call plot(xp,t1,2)
149  call plot(xp,yp,3)
  if(abs(xval-xmin) .gt. xres) go to 142
c
999  print 100,xlng,xmin,xmax,xtic1,xtic2,ndx,
$      ylng,ymin,ymax,ytic1,ytic2,ndy
100  format('0Error in BORDR2:/
$      '0xlng, xmin, xmax, xtic1, xtic2, ndx = ',1p5e11.3,i5/
$      '0ylng, ymin, ymax, ytic1, ytic2, ndy = ',1p5e11.3,i5)
  call pltend
  stop
end

```

```

        subroutine curve(x,y,up,nrpts,xmin,ymin,xinc,yinc,line)
c
c x,y,up must be dimensioned at least nrpts
c xmin,ymin are x,y origin in user units
c xinc,yinc are x,y scales in user units per inch
c
c line=1: solid
c      2: long dash
c      3: medium dash
c      4: short dash
c      5: dotted
c      6: short + long dash
c      7: short + short + long dash
c
c logical up,up1,up2
dimension ipen(8),joc(7),x(nrpts),y(nrpts),up(nrpts)
data ipen/2,2,2,3,2,3,2,3/,joc/18, 11, 14, 23, 32, 41, 16/
data delr/.1/
c
c      if(nrpts .le. 1) go to 99
c
c      if(line) 1,2,3
1      kk=mod(line,7)+7
      go to 4
2      kk=0
      go to 4
3      kk=mod(line,7)
4      kk=kk+1
      jo=joc(kk)/10
      jc=joc(kk)-10*jo
      ip=ipen(jo)
c
c      j=0
c      dr=0.
c      rho1=0.
c      rho2=delr
c      px1=(x(1)-xmin)/xinc
c      pyl=(y(1)-ymin)/yinc
c      up1=up(1)
c      if(.not. up1) then
c
c      go to first position with pen up
c      call plot(px1,py1,3)
c      if(kk .eq. 6) then
c          px2=(x(2)-xmin)/xinc
c          py2=(y(2)-ymin)/yinc
c          delx=px2-px1
c          dely=py2-py1
c          rho=sqrt(delx**2+dely**2)
c          if(rho .eq. 0.) then
c              dx 6-delx*.1
c              dy 6-dely*.1
c          else
c              dx 6-delx*delr/rho*.1
c              dy 6-dely*delr/rho*.1

```

```

        end if
        call plot(px1+dx6,py1+dy6,2)
    end if
end if

c
do 40 i=2,nrpts
px2=(x(i)-xmin)/xinc
py2=(y(i)-ymin)/yinc
up2=up(i)
if(up2) then
    dr=0.
    rho1=0.
    rho2=delr
    go to 39
end if
if(up1) then
c pen has been up, prepare to lower pen
    call plot(px2,py2,3)
    go to 39
end if
if(kk .eq. 2) go to 38
delx=px2-px1
dely=py2-py1
rho=sqrt(delx**2+dely**2)
rho1=rho1+rho
if(rho2 .gt. rho1) go to 38
delx=delx*delr/rho
dely=dely*delr/rho
dx 6=delx*.1
dy 6=dely*.1
if(dr .eq. 0.) go to 20
dx=delx*dr/delr
dy=dely*dr/delr
px1=px1+dx
py1=py1+dy
go to 21
20 if(rho2 .gt. rho1) go to 38
px1=px1+delx
py1=py1+dely
21 call plot(px1,py1,ip)
if(kk .eq. 6) call plot(px1+dx6,py1+dy6,2)
j=j+1
ip=ipen(jo+mod(j,jc))
rho2=rho2+delr
go to 20
38 call plot(px2,py2,ip)
dr=rho2-rho1
39 px1=px2
py1=py2
up1=up2
40 continue
99 return
end

```

**APPENDIX B—PROGRAM LISTING OF “TACAMO”**

```

c      TACAMO: TOWLINE CONFIGURATION CODE FOR TOWPLANE IN STEADY STATE
c      CONFIGURATION...towplane in circular orbit...(HUANG,NADC-
c      AM-6849,June 1969)
c
c      v      towplane true airspeed,knots
c      rpl    towplane turn radius(feet) for straight and level flight
c      zpl    towplane density altitude ft.
c      amg    drogue weight,lbs.
c      abase   drogue base area,sq. ft.
c      cddrog  drogue drag coefficient
c      amug   towline weight,lb/ft
c      d      towline diameter,ft.
c      al     towline length,ft.
c      picf   towline skin friction coefficient
c      cd     towline drag coefficient
c      x      distance from towpoint to drogue center of gravity,ft.
c      xcp    distance from towpoint to drogue center of pressure,ft.
c      alpha   pitch angle of drogue centerline(radians),positive is nose up
c      cappal  side slip angle in radians,towpoint left positive
c
c
c      namelist/datum/v,rpl,zpl,al,rzd,zzd,amg,itrset
c
c      dimension dsstor(17)
c
c      data g/32.17/,pi/3.1416/,acl/.53/,acm/- .68/,x/1.34/,xcp/2.31/,
c      $      abase/5.6/,cddrog/.6/,amug/1.095e-1/,d/1.75e-2/,dds/1.e3/,
c      $      picf/2.2e-2/,cd/1.03/,delr/5./,delz/50./
c      data dsstor/50.,130.,4*200.,4*300.,4*400.,2*600.,1000./
c
c      read datum
c      iter=1
c      print 1101,v,rpl,zpl,rzd,zzd
c      print 1102,amg,abase,cddrog
c      print 1103,amug,d,al,dds,picf,cd
c      ddrog=sqrt(4.*abase/pi)
c      if(cd .le. .1)stop
c      k=1
c      index=0
c 5 iter=iter+1
c      if(iter .gt. 30) then
c          print 1000
c          stop
c      endif
c 16 continue
c      zz=zzd
c      rz=rzd
c      i=1
c      ds=20.
c      omega=v*1.69/rpl
c      m=1
c      arg=1.-.006875*zz/1000.
c      if(arg .gt. 0.)then
c          rhoz=0.002378*arg**4.256
c      else

```

```

        print *, 'does not converge'
        stop
    end if
    omegsq=omega*omega
    s=0.
    thz=0.
    qs=.5*rhoz*rz*rz*omegsq*abase
    a=0.5*amg*x/qs+acl*x*.04
    b=(acl+cddrog)*x-ddrog*acm
    c=-0.04*acl*x-amg*x/qs
    alpha=(-b+sqrt(b*b-4.*a*c))*.5/a
    if(alpha .ge. .8) then
        a2=.85*qs*xcp
        b2=-amg*x-.85*pi*qs*xcp
        c2=amg*x*pi*.5-.85*qs*xcp
        alpha=(-b2-sqrt(b2*b2-4.*a2*c2))*.5/a2
        m=2
        am=amg/g
    endif
    al=-amg/g*rz*omegsq-qs*acl*.04
    bl=qs*(ddrog*acm/(x*cos(alpha))-acl-cddrog)
    cappal=al/bl
    if(cappal .le. .04) then
        trpz=-amg/g*rz*omegsq
    else
        trpz=-amg/g*rz*omegsq+acl*(cappal-.04)*qs
    endif
    if(alpha .le. .04) then
        tzpz=amg
        trthpz=0.5*rhoz*abase*cddrog*rz*rz*omegsq
    else
        if(m .eq. 1) then
            tzpz=amg-acl*(alpha-.04)*qs
            trthpz=0.5*rhoz*abase*cddrog*rz*rz*omegsq
        else
            if(m .ne. 2) stop
            tzpz=amg-.85*qs*sin(alpha)**2.*cos(alpha)
            trthpz=.85*qs*sin(alpha)**3.
        endif
    endif
    tz=sqrt(trpz*trpz+trthpz*trthpz+tzpz*tzpz)
    rpz=trpz/tz
    thpz=trthpz/(tz*rz)
    zpz=tzpz/tz
    rthpz=thpz*rz
    if(mod(index,3) .eq. 0 .or. k .eq. 4)then
        print 1
        print 21,s,rz,zz,thz,tz,RPZ,zpz,rthpz
    end if
8 s=s+ds
z=zz
t=tz
r=rz
rp=rpz
thp=thpz

```

```

      zp=zpz
      kk=1
10 za=.5*(z+zz)
      ta=.5*(t+tz)
      ra=.5*(r+rz)
      thpa=.5*(thp+thpz)
      zpa=.5*(zp+zpz)
      rpa=.5*(rp+rpz)
      arg=1.-.006875*za/1000.
      if(arg .gt. 0.)then
        rho=.002378*(1.-.006875*za/1000.)**4.256
      else
        print *, 'does not converge'
        stop
      end if
      thpasq=thpa*thpa
      rasq=ra*ra
      qd=.5*rho*d*rasq*omegsq*cd
      strth=sqrt(1.-rasq*thpasq)
      trp=(ta*ra*thpasq-amug/g*ra*omegsq-qd*ra*rpa*thpa*ctrth)*ds+trpz
      trthp=(-ta*rpa*thpa+qd*strth**3.+.5*rho*d*picf*rasq*omegsq)*ds+
$      trthpz
      tzp=(amug-qd*ra*thpa*zpa*strth)*ds+tzpz
      t1=sqrt(trp*trp+trthp*trthp+tzp*tzp)
      rpl=trp/t1
      rl=rz+(rpl+rpz)*.5*ds
      thpl=trthp/(t1*rl)
      zpl=tzp/t1
      zl=zz+.5*(zpl+zpz)*ds
      rthpl=thpl*rl
      thl=thz+(thpz+thpl)*.5*ds
      if(abs((zl-z)/z) .gt. .001) go to 100
      if(abs((rl-r)/r) .gt. .001) go to 100
      if(abs((t1-t)/t) .gt. .001) go to 100
32 if(l .le. i .and. i .le. 17) then
      ds=dsstor(i)
    else
      if(i .eq. 18) then
        if(s-al+1.0e-4 .eq. 0.0) then
          ds=dds
        else
          if(s-al+1.0e-4 .lt. 0.0) then
            go to 50
          else
            go to 190
          endif
        endif
      else
        print *, ' i is not between 1 and 18'
        stop
      endif
    endif
    i=i+1
50 zz=zl
    rz=rl

```

```

tz=t1
rpz=rpl
thpz=thpl
zpz=zpl
thz=th1
trpz=trp
trthpz=trthp
tzpz=tzp
if(al-s .lt. 1000.)ds=al-s
if(k .eq. 4)print 21,s,r1,z1,th1,t1,rpl,zpl,rthpl
go to 8
100 if(kk .gt. 20) then
    print 3
    go to 32
  endif
  z=z1
  r=r1
  t=t1
  rp=rpl
  thp=thpl
  zp=zpl
  rthp=rthpl
  kk=kk+1
  go to 10
190 continue
if(mod(index,3) .eq. 0 .or. k .eq. 4)then
  print 21,s,r1,z1,th1,t1,rpl,zpl,rthpl
  end if
  if(iter .gt. itrset)go to 18
  go to(200,203,18,1199),k
200 if(abs((z1-zpl)/zpl)-.010)202,210,210
202 go to(204,240),k
203 if(abs(z1-zpl)-2000.)204,204,210
204 if(abs((r1-rpl)/rpl)-.003)206,220,220
206 go to(240,200),k
210 k=1
  zzd=zzd+.6*(zpl-z1)
  go to 5
220 if(k .eq. 1) then
    drzd=.16*(rpl-r1)
  else
    if(k .eq. 2) then
      if(abs((r1-rstore)/rpl) .le. .002) drzd=.2*(rpl-r1)
      drzd=(rpl-r1)*drzd*.6/(r1-rstore)
      if(abs(drzd) .gt. 150.) then
        drzd=150.*drzd/abs(drzd)
      else
        if(abs(drzd) .le. 5.) drzd=5.*drzd/abs(drzd)
      endif
    else
      print *, ' k is not 1 or 2'
      stop
    endif
  endif
  rzd=rzd+drzd

```

```

k=2
rstore=r1
go to 5
240 k=3
18  continue
if(index .gt. 30)go to 999
if(istop .eq. 500)go to 1199
if(mod(index,3) .eq. 0)then
  if(abs((z1-zp1)/zp1) .lt. .001 .and. abs((r1-rp1)/rp1) .lt.
$   .001)go to 17
  f1=z1-zp1
  f2=r1-rp1
  print *, 'f1=' ,f1
  print *, 'f2=' ,f2
  z1sav=z1
  r1sav=r1
  zzdsav=zzd
  rzdsav=rzd
  zzd=zzd+delz
  index=index+1
  go to 16
else
  if(mod(index,3) .eq. 1)then
    dzldzd=(z1-z1sav)/delz
    drldzd=(r1-r1sav)/delz
    zzd=zzdsav
    rzd=rzdsav+delr
    index=index+1
    go to 16
  else
    dzldrd=(z1-z1sav)/delr
    drldrd=(r1-r1sav)/delr
    den=dzldzd*drldrd-drldzd*dzldrd
    delzd=(f2*dzldrd-f1*drldrd)/den
    delrd=(f1*drldzd-f2*dzldzd)/den
    zzd=zzdsav+delzd
    rzd=rzdsav+delrd
    index=index+1
    go to 16
  end if
end if
17  k=4
print 1301
print 1101,v,rp1,zp1,rzd,zzd
print 1102,amg,abase,cddrog
print 1103,amug,d,al,dds,picf,cd
print 1203,alpha,cappal
istop=500
go to 16
1199 stop
999 print *, 'does not converge'
stop
c
1 format(1h ,5x,1hs,11x,1hr,11x,1hz,11x,2hth,10x,1ht,10x,2hrp,10x,
$           2hzp,9x,4hrthp)

```

```
2 format(8e12.4)
21 format(8e12.4)
3 format(13h not converge)
1000 format(1h1,14hr1not converge)
1101 format(1h ,8hv(knot)=,e12.4,2x,4hrpl=,e12.4,2x,4hzpl=,e12.4,2x,
$      4hrzd=,e12.4,2x,4hzd=,e12.4)
1102 format(1h ,4hamg=,e12.4,2x,6habase=,e12.4,2x,7hcddrog=,e12.4)
1103 format(1h ,5hamug=,e12.4,2x,2hd=,e12.4,2x,3hal=,e12.4,2x,4hdds=,
$      e12.4,2x,5hpicf=,e12.4,2x,3hcd=,e12.4)
1203 format(1h ,3x,6halpha=,e12.4,5x,7hcappal=,e12.4)
1301 format(1h1,5x,3hrpl,9x,5hrdrog,7x,3hzpl,9x,5hzdrog,7x,3hsep,9x,
$      1ht,1lx,4hrpp1,8x,4hzpp1,8x,4hthp1)
c
end
```